Specification of users' cognitive functions and emotions to promote their improvement through serious games

Abstract

Serious games are gaining recognition as a powerful tool for promoting education. However, creating games that effectively enhance cognitive and affective outcomes requires a methodological approach. This paper presents a cognitive-affective model for conceptualizing the design of serious games. The model comprises two dimensions - cognitive and affective - each with its graphical notation, components, and behavior. The cognitive dimension is based on neuroscience and game mechanics research, while the affective dimension is drawn from affective computing.

This paper explores the relationship between game mechanics and cognition. It shows how the cognitive-affective model can guide the development of games that facilitate continuous training and generate cognitive experiences in specific situations. A case study highlights the model's effectiveness in a gas explosion simulation explicitly designed for the mining sector. The model enables designers to create games that train users in risky situations, improving their behavior in simulated dangerous situations in a safe environment. Overall, this paper contributes to serious games by providing a practical and comprehensive model for designing effective serious games.

1 Introduction

Games significantly impact cognitive abilities, particularly memory, with conversational and observational activities showing greater effectiveness than writing exercises, as noted by (Núñez Castellar et al., 2015) and (Kim et al., 2009). Therefore, measuring the efficiency of games in a game-based learning context, with follow-up time with learners included, is crucial, as (All et al., 2021) emphasized. Additionally, it is important to explore individual differentiating aspects that may affect the user's reaction to the game, as (Yang & Chen, 2020) discussed.

Serious Games (SG) have become increasingly popular in education and training contexts due to their effectiveness in enhancing learning outcomes by integrating simulation, game mechanics, gamification, and pedagogical components to enhance the user's experience and mitigate learning-related issues such as attention, concentration, and memory. While educational games are valuable tools for learning, developing them to integrate learning analytics and assessment is complex. They have simplified game mechanics development for specific genres and games through architectural solutions and software engineering (Nelson et al., 2021) and (Mizutani et al., 2021). SG is an effective tool for teaching technical and soft skills, crisis management, and improving behavior while reducing training costs (Daoudi et al., 2021). Besides, SG can help individuals enjoyably and educationally develop new skills, making learning a more rewarding experience.

LudoMinga, a cognitive training program developed by (Santórum et al., 2021), consists of a set of mini-games designed to enhance cognitive abilities in individuals with intellectual disabilities. The program follows a user-centered approach based on the iPLUS methodology, which includes five phases (Carrión et al., 2020): 1) Identification, 2) Pedagogical Objectives, 3) Playful Game Scripting, 4) Playability, and 5) Refinement. During the Pedagogical Objectives phase, the iPLUS methodology defines general and specific learning objectives for developing academic competencies. This includes the specification of cognitive skills such as memory, concentration, and perception. While the iPLUS methodology employs a pedagogical expert to define objectives and a facilitator to establish the cognitive skills and aptitudes to be developed, it currently lacks a mechanism for specifying the user's cognitive and affective skills.

Serious games are an effective tool for enhancing players' learning experience (Silva, 2020). To make serious games more appealing to players, Silva suggests a methodology for defining the learning mechanisms of educational games. This methodology involves several steps, from selecting the appropriate topic to enhancing the user experience. The methodology involves separating learning content from other game mechanics, allowing players to focus on both the game and the learning objectives. The process includes developing the main game and adding learning layers, which can be achieved through puzzles and trivia. (Najoua & Mohamed, 2018) propose a methodology called KASP for developing serious games for children with learning difficulties. KASP is based on four pillars, namely Knowledge, Affect, Sensory, and Pedagogy, and incorporates cognitive and affective aspects to improve the learning process through play and interactivity. However, the methodology does not specify the necessary cognitive functions to control basic emotions affecting learning.

(Serrano-Laguna et al., 2018) developed a methodology to evaluate the effectiveness of serious games in achieving learning outcomes. The four-stage methodology includes design, implementation, validation, and deployment. The design phase involves defining learning objectives and identifying the target audience. Learning mechanics are designed and combined with learning outcomes during the implementation phase. The validation phase involves the participation of experts and a target audience sample to ensure reliable learning outcomes. Once validated, the game is ready for deployment. However, the methodology does not specify the cognitive functions necessary to achieve the proposed learning objectives.

Considering that our work focuses on the cognitive and affective dimensions of the user using serious games, we present a theoretical framework of cognitive functions, together with the theoretical basis of emotions. The theoretical framework of cognitive functions and their relationship with memory and attention (Ben-Sadoun & Alvarez, 2022) identifies connections between game mechanics and cognitive functions, specifically executive functions. The framework provides a set of building blocks (metabricks) for video games that target executive functions. The correspondence between game mechanics and cognitive stimuli can help prevent cognitive decline or neurodegenerative diseases. However, the proposal does not specify the user's training or cognitive stimulation. In contrast, our model has the component of complementary activities associated with the game's mechanics to strengthen cognitive training. Therefore, we review which of the 14 metabricks matches with executive functions from (Ben-Sadoun & Alvarez, 2022) and take some of them to model the behavior between the game mechanics component and the complementary activities of the model. Since the others did not apply to our study, we used model specification mechanics related to inhibitory control (e.g., move, avoid, shoot, write, transform, and vocalize).

This research aims to develop a comprehensive cognitive-affective model to improve the cognitive and affective functions of users using serious games. The model specifies executive cognitive functions such as inhibitory control, cognitive flexibility, and working memory, and basic cognitive functions like attention, perception, and memory, based on the work of (Diamond, 2013). Additionally, the model's affective dimension is based on two categories: basic emotions (Picard, 2000) and secondary emotions (Plutchik, Robert; Kellerman, 2013). This categorization is based on the idea that all human cultures have a set of basic universal emotions that are innate and shared. In contrast, secondary emotions are derived or more complex. Some commonly accepted basic emotions include happiness, sadness, fear, anger, surprise, and disgust. In contrast, secondary emotions can be envy, shame, guilt, pride, hope, or gratitude.

Our proposed model includes specific components for training cognitive experience and regulating emotions, which considers the importance of emotions in the learning process. The model is based on expert neuropsychologists' theories. The model's cognitive and affective dimensions are grounded in theories of cognition and emotion (Power & Dalgleish, 2016), theories of emotions (Najoua & Mohamed, 2018), executive functions (Diamond, 2013), and a theoretical framework (Ben-Sadoun & Alvarez, 2022). The model's emotion specification includes the foundations of affective computing (Aguilar et al., 2020). The main contributions of this research are: 1) Provide a design of the cognitive dimension to train users in cognitive functions through serious games. 2) Design the affective dimension with the necessary components to evaluate the user's behavior in the face of a dangerous event or situation using serious games.

This paper's structure includes a description of theoretical foundations in Section 2, followed by the research method in Section 3, which details the cognitive and affective dimensions and their components. Section 4 presents a case study in the mining sector, including the cognitive and affective dimensions' specification using a virtual reality simulation of a coal mine explosion. The main conclusions are presented in Section 5.

2 Theoretical framework

This section presents the theoretical framework of cognitive functions, emotions, gamification, and serious game development methodologies.

2.1 Cognitive Functions

Cognitive Functions (CF) are cognitive-behavioral activities that can be improved through practice and cognitive stimulation. CFs are classified as basic (Perception, Attention, and Memory) and complex (Praxia, Language, and Executive Functions) (Brusco, 2018).

2.1.1 Basic cognitive functions

Perception is an individual process carried out by living beings and consists of receiving, processing, and interpreting stimuli from the environment and within themselves (Brusco, 2018). It is a process that transforms raw input into the system's internal representation for carrying out cognitive tasks (Kotseruba et al., 2016).

Attention is the process of the mind taking clear and vivid possession of one of several possible objects or lines of thought (Lindsay, 2020). Despite the many definitions of attention, it is crucial for information processing in the brain and, increasingly, in artificial systems. Attention can be categorized into two types: external and internal. External or perceptual attention selects and modulates information from various senses. Internal attention modulates internally generated information, such as the contents of working memory or a set of possible behaviors in a given context (Kotseruba et al., 2016). According to (Echavarría Ramirez, 2013), attention is the process responsible for establishing an order of priorities and temporarily sequencing the most appropriate responses for each occasion. Attention is a property of the nervous system that directs the complex actions of the body and the brain.

Memory is a human's capacity to acquire, store, and remember information. Memory is a psychological process responsible for our identity and guiding our daily life (Mourão & Faria, 2015). It is related to other functions, such as executive function and learning. Therefore, memory is a cognitive resource that we always use. Depending on the nature of the memories, memory can be classified into sensory, working, and long-term.

2.1.2 Complex cognitive functions

Praxia is the succession of coordinated movements for the achievement of an aim. It is the ability to execute a learned motor action. Also, it is the ability to perform a voluntary, intentional, and purpose-directed movement (Brusco, 2018).

Language is the ability of human beings to communicate using linguistic signs (sounds, gestures, signs, and graphic signs). Language has multiple variables and components: fluency, comprehension, nomination, musicality, grammar, etc. (Brusco, 2018).

Executive Functions (EF) are the skills that allow setting goals and achieving them by planning and controlling the progress, inhibiting thoughts, behaviors, and emotions that interfere with their achievement. It is a concept that encompasses the use of specific cognitive functions or skills that are interrelated. The core executive functions include Inhibitory Control, Working Memory, and Cognitive Flexibility (Santa-Cruz & Rosas, 2017). EFs are also known as executive control or cognitive control. *"EFs are essential skills for mental and physical health; success in school and life; and cognitive, social, and psychological development"* (Diamond, 2013).

2.2 Emotions

Emotion is an intense and transient mood alteration, pleasant or painful, accompanied by a certain somatic commotion. Emotions are functional states implemented in the activity of neural systems, which regulate complex behaviors (Adolphs, 2017). According to Barrett's theory, emotions are socially constructed from physical changes that take on psychological functions they cannot perform independently. Barret argues that understanding the social, psychological, and biological factors that contribute to emotional episodes is key to understanding the nature of emotion as a whole (Barrett, 2012).

Basic universal emotions are those feelings that we first perceive to be instantly responsive to a situation (Zhu et al., 2021). The basic universal emotions, including anger, disgust, fear, happiness, sadness, and surprise, are either positive or negative. While happiness and surprise are positive, anger, disgust, fear, and sadness are negative emotions (Aguilar et al., 2020).

Secondary emotions are discrete and more complex than basic emotions. They include cognitive assessments and refer to the mental model that the person has of himself/herself and others. Some secondary emotions cover both positive and negative affects at the same time. These secondary emotions are numerous, there is no standardization of them. The most frequent secondary emotions are nostalgia, empathy, shock, astonishment and tenderness (Braniecka et al., 2014). Secondary emotions appear after basic emotions. They can be directly caused by the basic emotions or come from a more complex chain of thought (Zhu et al., 2021).

2.3 Gamification

Gamification is a technique that utilizes game mechanics or elements to modify behavior and motivate individuals to achieve specific objectives. This approach generates fun, feedback, learning, and commitment in participants (González Jorge, 2016). Werbach notes that while gamification is attractive for professionals and researchers, the field's contours remain uncertain. Werbach defines gamification as *"the process of making activities more like a game"* focuses on the components of games and the gameplay experience (Werbach, 2014). The structure of gamification elements involves three levels: basic components, mechanics, and game dynamics. These elements are present from the beginning to the end of the activity and contribute to the participant's enjoyment, motivation, and engagement. This framework has been widely used in gamification (Barriales et al., 2020).

2.4 Serious game development methodologies

To describe the design and development of serious games, it is essential to conceptualize development methodologies. A development methodology refers to the steps, techniques, phases, and processes used to develop a video game. For example, a video game can be developed using general software development methodologies (De Lope et al., 2015).

It is crucial to understand the difference between video games and serious games. According to (Mettler & Pinto, 2015), a serious game is a computer game designed for educational purposes, solving real-world problems in a fun way (Udjaja Yogi & Ramdhan Dimas, 2023). Conversely, video games aim to keep the player entertained and engaged without predefined learning objectives. The initial definition of a serious game was coined by (Clark, 1970), referring to computer games with explicitly educational purposes. In this paper, we will present serious game development methodologies.

EMERGO is a personalized methodology designed to facilitate the developing and delivering serious games for higher education learning (Nadolski et al., 2008). This methodology offers a generic toolkit for the efficient creation of serious games, which are multimedia cases that assist learners in acquiring complex cognitive skills or competencies. EMERGO provides an online, practice-based environment for active and cooperative learning, where learners engage with real-life problem situations and observe the consequences of their actions. This personalized learning experience can be highly motivating for learners. It is noteworthy that EMERGO does not explicitly specify the cognitive functions necessary to enhance learning in higher education. Instead, the methodology focuses on acquiring complex cognitive skills through serious games.

Designing and developing serious games through the methodology of mini-games can provide motivating learning experiences and enhance the reinforcement of learning objectives (Barbosa et al., 2014). In this methodology, the learning contents are distributed in layers throughout the game, and the player must complete missions and overcome learning mechanisms in each layer. This approach to serious game development offers a structured progression of levels that engage the player in a fun and interactive learning experience.

The KASP methodology (Najoua & Mohamed, 2018) is designed to support serious game designers in creating learning games for children with learning disabilities. The methodology is based on four pillars: Cognitive, Affective, Sensory, and Pedagogy, and consists of five phases: preliminary analysis, conceptual architecture, prototyping, testing and validation, and development. To implement KASP, a specialized medical team must first provide a diagnostic model for each child with learning disabilities. The methodology follows a systematic process for each of the four pillars, ensuring the audience's needs are fully addressed. By incorporating the four pillars and a comprehensive methodological process, this methodology can help serious game designers create effective learning games that meet the unique needs of this audience.

(Silva, 2020) proposes a practical methodology for designing educational serious games that focuses on defining learning mechanisms and game characteristics. This methodology consists of two levels: the first pertains to the main game, and the second includes the learning layers. The methodology begins with selecting the theme and learning objectives, then determining the target audience, learning styles, game genre, story, scenarios, and characters. The learning layers are integrated into the main game to differentiate game mechanics from learning mechanics, and the dynamics and learning outcomes are established. The methodology also emphasizes user experience and enjoyment based on gamification principles. However, it does not address cognitive functions in the learning process. Its primary goal is to make the game fun and engaging while facilitating communication between game developers and pedagogical experts.

(Carrión et al., 2020) introduce the iPLUS methodology, which emphasizes participatory and user-centered design, and comprises five phases: identification, pedagogical objectives, game scripting, gameplay, and refinement. The methodology involves experts, users, and facilitators in all phases and refines user stories. Additionally, iPLUS presents a metamodeling approach that allows for component extensions and specializations, making it an agile and flexible methodology. In light of iPLUS's metamodeling, this paper proposes extending or adding cognitive and affective dimensions to iPLUS to develop serious games that stimulate cognitive functions and regulate emotions in specific mining situations.

3 Method

This article employs a three-phase research method. Phase 1 examines serious game development methodologies related to the object of study using an exploratory research scope (Olave et al., 2014). Phase 2 constructs a cognitive-affective model, describing the behavior and components of the cognitive and affective dimensions through a descriptive research focus (Olave et al., 2014). Finally, phase 3 designs a case study of three activities, including defining an example in the mining field, applying the cognitive-affective model, and delivering results (see **¡Error! No se encuentra el origen de la referencia.**).

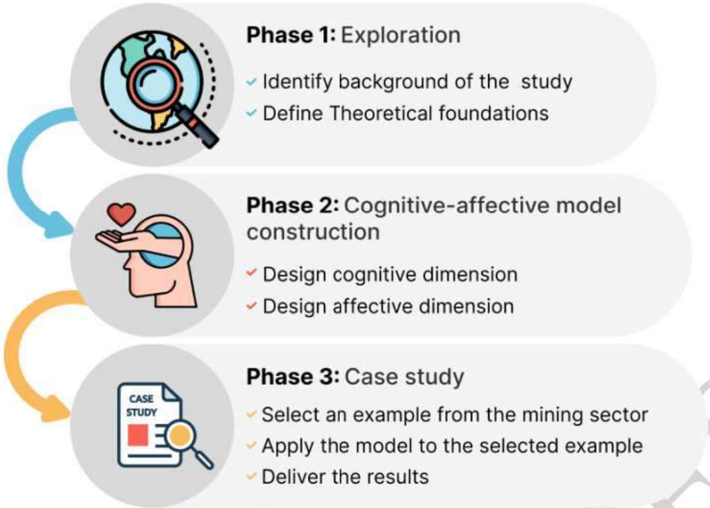


Figure 1. Methodology designed for the investigation

Section 1 provided background information, and Section 2 outlined the theoretical framework, including cognitive functions, emotions, gamification, and serious game development methodologies. Section 3 describes the construction of the cognitive-affective model, which includes designing the cognitive and affective dimensions. The cognitive dimension focuses on memory, attention, perception (Kotseruba et al., 2016), the central executive functions (Diamond, 2013), and some mechanics, such as move, select, shoot, write, and avoid (Ben-Sadoun & Alvarez, 2022), while the affective dimension incorporates affective computing theory (Picard, 2000) and (Aguilar et al., 2020) and philosophical and psychological approaches (Power & Dalgleish, 2016). Section 4 outlines the case study and includes four subsections: context, identification of model components, cognitive and affective dimension specification, and an example game.

3.1 Cognitive Dimension

The cognitive dimension corresponds to the specification of the components of the cognitive process of users using serious games as a training tool. The cognitive dimension of the model is based on the central executive functions theoretical framework (Diamond, 2013) and the game mechanics and cognitive functions matching framework (Ben-Sadoun & Alvarez, 2022).

The **Cognitive Test** evaluates the user's **Cognitive Function** through various **Psychological Tasks** that measure cognitive function **Level**, which can be **Basic Cognitive Functions** or **Complex Executive Functions** and generates **Capabilities**. **Complementary Activities** are required for optimal cognitive function performance, developed using **Mechanics** like games, challenges, mazes, and computer applications. The Cognitive Function serves as the central component of the model (see **¡Error! No se encuentra el origen de la referencia.**).

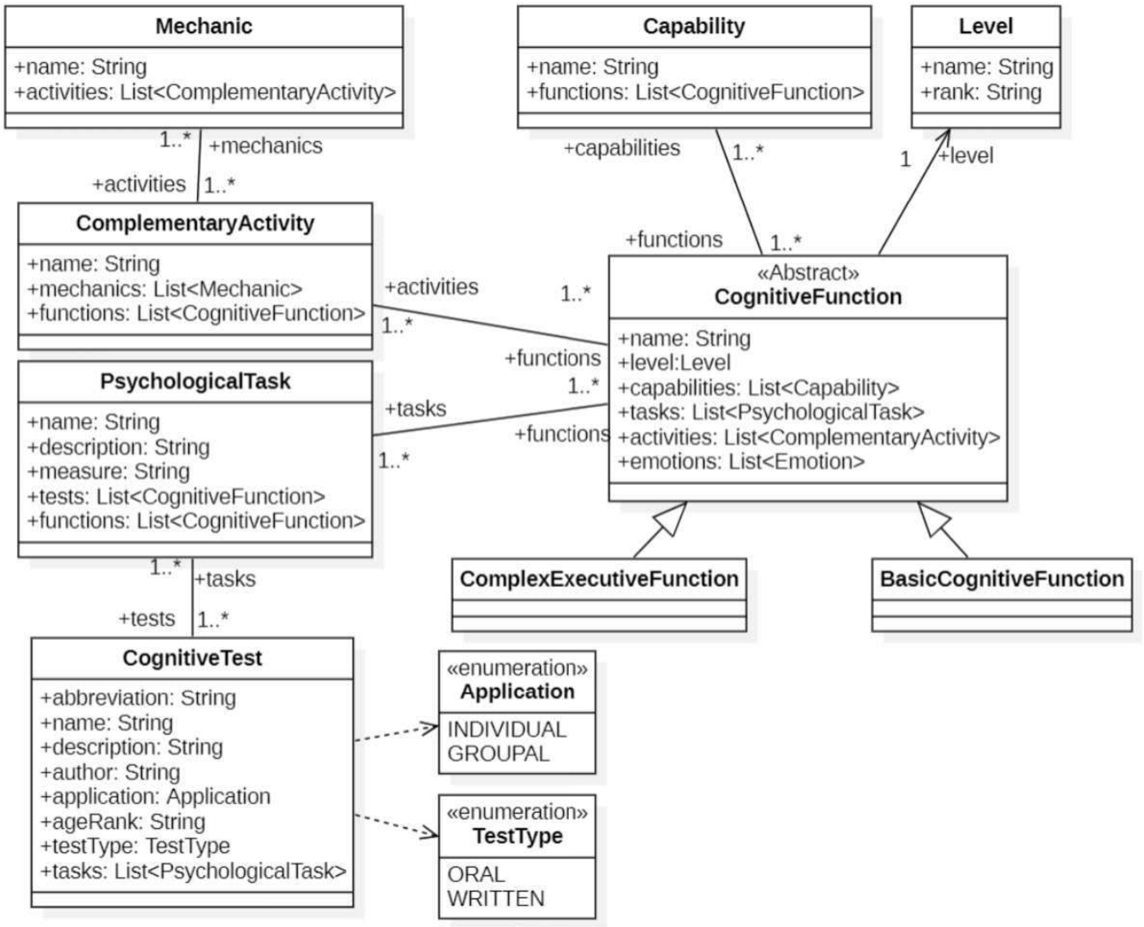


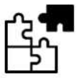
Figure 2. Cognitive dimension model

Table 1, which includes the components of the cognitive dimension, their graphic notation, and highlighted attributes in the description. It provides a comprehensive understanding of the cognitive dimension by presenting a detailed description accompanied by graphical representations.

Table 1. Cognitive dimension components

Cognitive Function	
Graphical notation	**Description**
	This component denotes the activities that can be improved through regular practice and cognitive stimulation. The name attribute pertains to the title assigned to the cognitive function, which serves as its identifier. The activities attribute comprises the complementary activities aimed at enhancing and training the cognitive function. The capabilities attribute denotes the capacity generated through cognitive training, resulting in improved performance of the function. Emotions link the cognitive and affective dimensions, which we will explore later. By bridging these two dimensions, emotions enable individuals to experience and regulate their feelings and thoughts, influencing their behavior and decision-making. The level attribute is an essential metric obtained from cognitive testing that indicates the cognitive function's proficiency level. This attribute is

	typically measured on a scale, and the value assigned can be low, medium, or high, depending on the test results. The tasks attribute refers to the psychological tasks used to assess the cognitive function's performance. Cognitive functions can be broadly classified into two types: basic and complex. **Basic cognitive functions** encompass perception, attention, and memory. **Complex cognitive functions** are related to praxis, language, and executive functions.
Cognitive Test	
Graphical notation	**Description**
	Cognitive or neuropsychological tests are essential in evaluating various cognitive functions associated with different brain activities. However, interpreting the results of these tests requires focusing on functional studies to accurately interpret the findings (Ardila & Ostrosky, 2022). The Cognitive Test component comprises several attributes, including its abbreviation used as a test identifier, which consists of numbers, letters, and signs. The ageRank attribute considers the age range for which the instrument was designed. The application attribute describes how the test is applied (i.e., individual or groupal). The author attribute denotes the person responsible for designing the test, and the description attribute briefly explains the test's purpose. The name attribute pertains to the title assigned to the cognitive test. The testType attribute describes how the test is performed (i.e., oral or written). In addition to these attributes, the Cognitive Test component includes the tasks attribute, which refers to the psychological tasks used to assess cognitive test performance. By incorporating these attributes, the Cognitive Test component facilitates a comprehensive evaluation of cognitive functions, aiding in accurately interpreting test results.
Psychological Task	
Graphical notation	**Description**
	This component encompasses attributes such as identifier, name, description, and measure, which are used to define and evaluate psychological tasks in the cognitive dimension of the model. The description attribute briefly explains the task (e.g., drawing a certain number of complex geometrical figures). The measure attribute specifies the mechanism for measuring the performance of the task (e.g., reaction time, drawing detail, number of hits, number of misses). The name attribute refers to the task's title, such as Stroop, Flanker, Simon, or Anticascade, among others. These attributes help identify, categorize, and evaluate psychological tasks for cognitive function assessment, facilitating the accurate interpretation of test results. A psychological task is an activity designed to assess the user's cognitive functions and is typically associated with one or more cognitive tests.
Capability	
Graphical notation	**Description**
	The Capability component represents the power or ability to do something. The attribute name refers to the title of the capability used to identify it (e.g., hazard detection, reaction ability, concentration ability, and others). Capabilities are generated by stimulated cognitive functions. For example, the cognitive function of perception generates the capability of hazard detection, while the cognitive function of attention generates the capability

	of reaction ability. By incorporating these attributes, the Capability component can facilitate a comprehensive evaluation of cognitive functions and aid in developing cognitive training programs.
Complementary Activity	
Graphical notation	**Description**
	This component pertains to activities or games designed to enhance cognitive functions through practice and stimulation. The attribute name denotes the title of the activity or game (e.g., labyrinths, hangman, driving, puzzles) intended to train and improve cognitive capabilities. The activities comprise a set of mechanics that improve a user's cognitive functions.
Mechanic	
Graphical notation	**Description**
	This component corresponds to the game mechanics or systems that develop and improve cognitive functions through complementary activities. The attribute name refers to the title of the mechanic (e.g., move, drive, write, select, drag, and drop). It is important to note that a single game may have one or more mechanics, which can be used across multiple complementary activities to enhance cognitive training. By incorporating these mechanics, the Complementary Activity Component facilitates the development of diverse and engaging cognitive games to improve cognitive functions.
Level	
Graphical notation	**Description**
	This component determines the level of cognitive function. The attribute name refers to the title of the level. The rank attribute represents the classification of the cognitive function based on the results of psychological tasks. This attribute can take on values such as high, medium, or low, depending on the level of cognitive function. By incorporating these attributes, the Level component can aid in tracking the progress of cognitive training and provide valuable insights into the effectiveness of cognitive interventions.

3.2 Affective Dimension

The affective dimension corresponds to the specification of components of the emotional processes of users using serious games as a training tool. We explain and visually represent the cognitive dimension's components and functioning. The affective dimension of the model draws upon the theoretical frameworks of affective computing (Picard, 2000) and (Aguilar et al., 2020), and the Aristotelian and Thomistic theory regarding emotions (Power & Dalgleish, 2016). Within this dimension, we categorize basic universal emotions: happiness, sadness, anger, fear, disgust, and surprise. These emotions are considered universal, as their inclusion is based on facial expressions, established by Ekman, Friesen, and Ellsworth (Power & Dalgleish, 2016).

The affective dimension of a serious game is activated when an **Event** occurs, eliciting emotions in the user. These **Emotions** have a two-dimensional **State** consisting of valence (pleasantness) and arousal (intensity). Valence ranges from very negative to very positive, rated on a nine-point scale. Arousal represents the intensity of the affective content, rated on a nine-point scale from 1 (neutral/objective) to 9 (very high). These emotions experiences by the user during gameplay are recognized through **Recognition Methods**, and the **Parameters** of these emotions are reflected in their **Behaviour**. Moreover, **Characteristics** (physiological changes) are observed in the user based on the characteristics of their behavior. Based on these components, we have designed the model presented in **¡Error! No se encuentra el origen de la referencia.**, where emotion is placed at the center of the affective dimension.

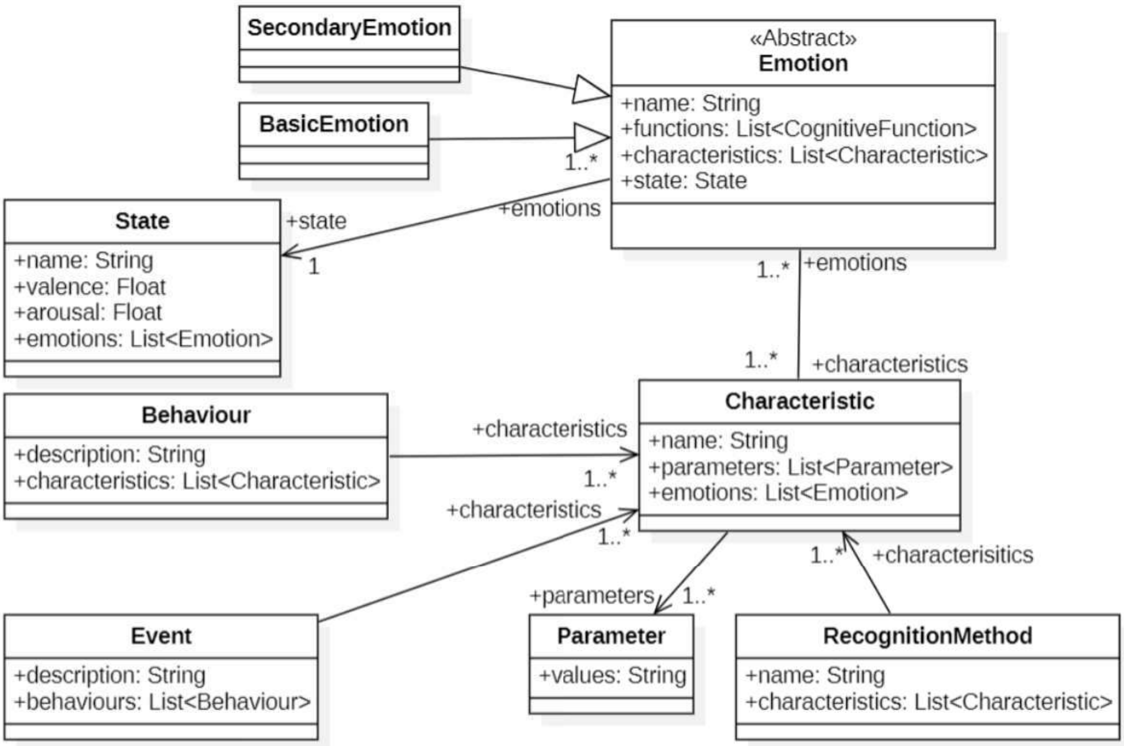
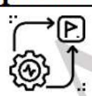


Figure 3. Affective dimension model

Table 2 describes the components of the affective dimension and their corresponding graphical notation. The component attributes are denoted by underlined text in the description.

Table 2. Affective dimension components

Event	
Graphical notation	**Description**
	This component refers to a specific event or situation that can be presented in a serious game to elicit emotions in the user. The description attribute allows for a detailed representation of the situation or event, providing context and information necessary to evoke the desired emotional response from the user. Some examples of situations that can be represented in a serious game to elicit emotions include mining accidents caused by explosions, landslides, gas and/or coal dust explosions, and floods. In an event, a user can present one or more behaviours.
Emotion	
Graphical notation	**Description**
	This component describes the emotion that a user presents to a given event. And they can be basic emotions or secondary emotions. The attribute name refers to the title of the emotion (e.g., happiness, surprise, sadness, anger, fear, and disgust). The attribute state represents the emotional state present in the individual (e.g., tense, happy, etc.). An emotion presents

	physiological characteristics that can be controlled by training the user's cognitive functions.
State	
Graphical notation	**Description**
	This component describes emotions in a two-dimensional space (valence and arousal). The attribute name refers to the emotional state's title, such as sad, happy, calm, and others. According to the American psychologist James Russell, recognized for his research in the field of the psychology of emotions and for the two-dimensional Russell model, the emotional state of the user depends on the value taken by the variables valence and arousal (Aguilar et al., 2020). The valence attribute in Russell's two-dimensional model refers to the affective evaluation of an emotion in terms of its positivity or negativity, represented on the horizontal axis ("X") of the model. While the arousal attribute refers to the level of energy or intensity associated with an emotion, represented on the vertical (Y) axis of Russell's model. For example, the emotional state of tension is characterized by a low negative valence and a high level of arousal. The attribute emotions refers to the set of emotions that the user experiences in a specific state.
Characteristic	
Graphical notation	**Description**
	This component corresponds to the physiological characteristics of the user. A characteristic has one or more parameters that define the user's emotions. The physiological characteristics can be acoustic (pitch, volume intensity, speed of speech), bodily (arms, head, fists, body, and gestures), and facial (eyes, mouth, nose, eyebrows, etc.) (Aguilar et al., 2020). The attribute name details the user's physiological changes and behavior.
Parameter	
Graphical notation	**Description**
	The parameter component presents attributes such as values. The attribute values refer to the value the characteristic takes in a specific event. This component takes a value (e.g., arms are body characteristics that take parameters with values such as crossed and raised).
Recognition Method	
Graphical notation	**Description**
	This component allows to detect the characteristics present in the user's emotions. The attribute name refers to the title of the recognition method (e.g., facial, body, etc.).
Behavior	
Graphical notation	**Description**
	This component describes the user's actions and the relationship between the characteristics or physiological changes resulting from the emotions. The attribute description comprises the set of physical and mental actions produced in an event.

3.3 Cognitive – Affective Model

In this section, we present the integration of the cognitive dimension (section 3.1) and the affective dimension (section 3.2). To integrate these two dimensions as show in Figure 4, we based on theories about the influence of cognitive functions on the regulation (control) of emotions (Li et al., 2022). The psychoevolutionary theory of emotion (Plutchik, Robert; Kellerman, 2013) recognized that functions are intimately related to emotions. (Plutchik, Robert; Kellerman, 2013) establish cognitive functions as the recognition or evaluation of good and bad aspects of an environment. Another theoretical study that reinforces the integration of cognitive and affective dimensions is Groos' theory of the emotional regulation process. Renowned psychologist James Gross argues that people can use cognitive strategies to regulate and modify their emotions (Aldao & Nolen-Hoeksema, 2013).

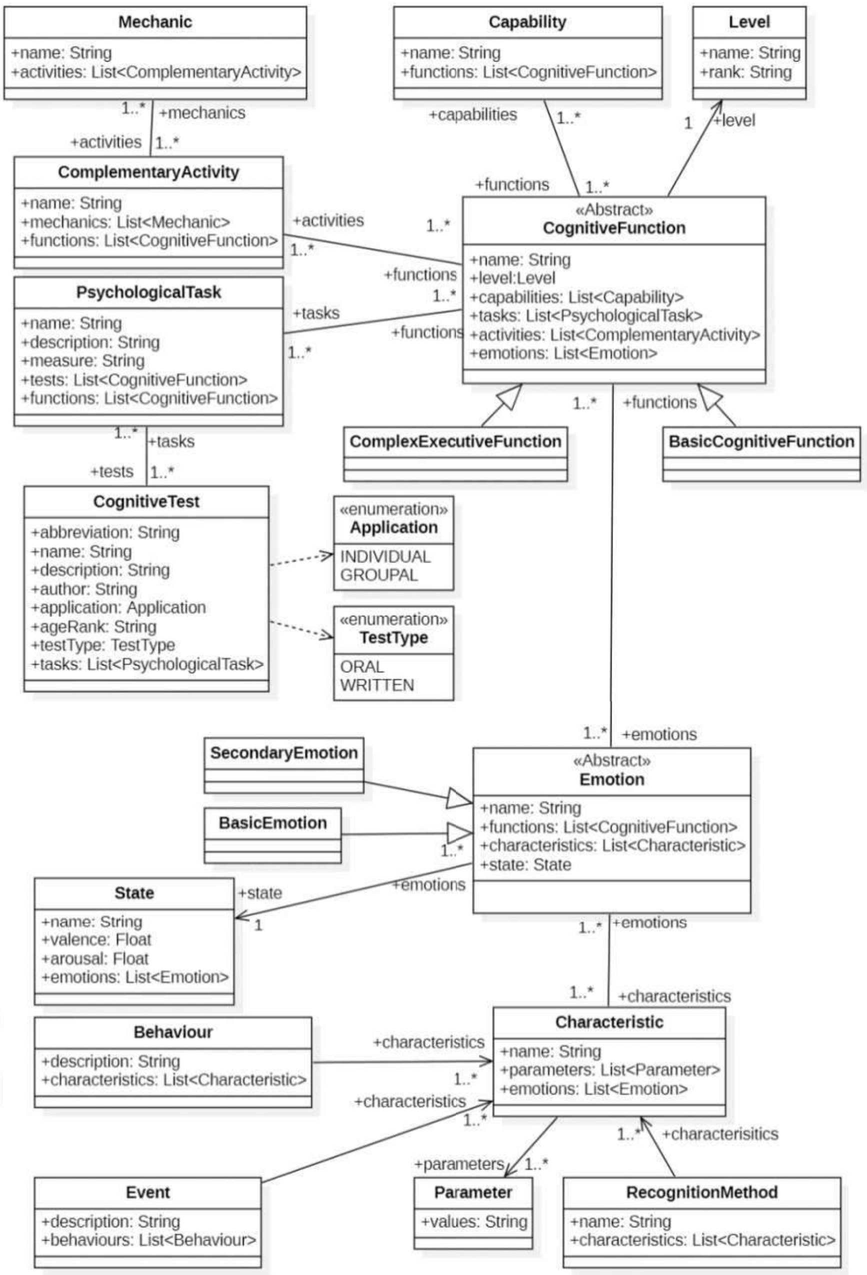


Figure 4. Cognitive Affective Model

4 Case Study

This chapter is presented in four sections. Section 1 shows the contextualization of the case study based on the lessons learned by the Colombian National Mining Agency (NMA), and Section 2 identifies the elements of the model in the situation presented in Section 1 for the cognitive and affective dimension specification. Section 3 shows the development of a virtual simulation of a gas explosion in a subway coal mine, allowing to validate that from the cognitive-affective model it is possible to design serious games for hazard training.

The Colombian National Mining Agency (NMA) has garnered valuable insights through a comprehensive lesson learned from a mining accident caused by an unfortunate explosion. This illuminating case study delves into the factors that played a role in the incident and offers compelling recommendations on preventive measures that could have been implemented.

4.1 Context of the case study

Mine A had established communication with mines B, C, and D. Ten workers entered mine A, where an unfortunate explosion occurred. At the time of the incident, six workers were concentrated in the turnstile, preparing to exit, while the remaining four were on the main level. The explosion resulted in the release of smoke, coal dust, and various other elements from the four manholes. The initial trigger was a primary methane explosion, which further intensified due to the presence of coal dust. Autopsy reports from experts revealed that the mining workers' cause of death was acute hypoxia[1].

The consequence was an explosion caused by methane gas (CH4) enriched with coal dust, leading to the tragic loss of ten miners from mine A and one miner from mine B. Additionally, four workers experienced severe intoxication. The immediate causes of the incident were that the mine lacked adequate support and lacked continuous monitoring of atmospheric conditions. The Basic cause due to personal factors was insufficient training. The basic causes due to occupational factors were low perception of risk, inadequate supervision, and inadequate assessment of the risk of which miners are exposed.

Ways to prevent these risk events include having technical personnel available for supervision before and during each shift in subway work and at work fronts. And train workers in the use and handling of equipment previous operation.

Miners confront a profound emotion characterized by the fear that permeates their existence, not merely a fleeting sense of fright but a deep-seated trepidation ingrained by the mining environment itself (unpredictable nature of mining operations). Fear remains an ever-present companion in their work, particularly within the confines of the mine, where latent risks loom. The mining worker must learn to navigate many hazards, encompassing sudden movements, explosives, and landslides. While engineers assert that advancements in equipment and tools have alleviated some of the hardships, the inherent danger persists as an ever-present reality that can culminate in an accident. Although mechanization has become integral to mining practices today, miners are still intimately acquainted with the emotion of fear. Today, part of the mining work is mechanized; however, the miner constantly lives the emotion of fear; when he is not in danger, he sees how his colleague is in danger (Méndez y Barrueta, 2011).

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[1] https://www.anm.gov.co/sites/default/files/DocumentosAnm/leccion_aprendida_explo_sub_carbon_cucunuba_cundinamarca_2020.pdf

4.2 Cognitive and affective dimension specification

Based on the description of the case study (Section 4.1), we can conclude that the **event** was a mining accident caused by an explosion, highlighting the inherent risks associated with mining activities. The case study reveals that one of the contributing factors to this incident was a low perception of risk among the personnel involved. To prevent similar events in the future, it is crucial to provide comprehensive training to mining personnel. Therefore, the specific **cognitive function** that needs to be addressed is perception. Additionally, the case study emphasizes that fear of danger is the predominant **emotion** experienced in mining work.

Once we have identified the central components of the model (the events, the cognitive functions, and the emotions), we proceed to identify the other components of the cognitive dimension and the affective dimension. Specifying these model components will allow cognitive stimulation and control of emotions in this situation.

- **Event:** Mining accident caused by an explosion

  Behaviour: Doing nothing, standing still

  Characteristics of standing still: arms, eyes. And these characteristics are presented in the emotions and produced according to the user's behavior.

  Parameters of Arms: with values of crossed

  Parameters of Eyes: with values opened, tearful

  Recognition methods to be used: body language (arms, head, gestures, etc.), face recognition(eyes, mouth, nose, eyebrows, etc.)

- **Basic Cognitive Function:** Perception
  Level: high

  Capability to be developed: Detect hazards or risks.

  Complementary activity: Labyrinths. These activities help to improve the user's perception. The development of complementary activities stimulates cognitive functions to control emotions.

  Mechanics of the complementary activity: move, avoid

  Psychological tasks to measure perception: copying nine geometric figures presented on 10 X 15 cm cards. These tasks are included in cognitive tests.

  Cognitive test: allows the inclusion of specific psychological tasks for the evaluation of cognitive functions. For this specification was taken Bender's test or the visuomotor gestalt test.

  Cognitive functions assessed by the Bender test: Visual perception and visual-motor coordination.

  Author: Laureta Bender (1938-1984),

Bender test abbreviation: BVGT (Bender's Visuomotor Gestalt Test)

Age range of cognitive test application: From four years of age

Test type: Written

Application method: Individual

- **Basic Emotion:** Fear

  State of emotion: Disturbed (valence = 0.0, arousal=2.5)

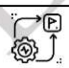
  Body characteristics that can be presented in the emotion of fear: arms, eyes, etc.

  Regulation of fear emotion reinforces cognitive function: Perception

Taking the example of the NMA, we specified the cognitive and affective dimensions of the proposed model as follows. The cognitive function to be trained is perception. Perception is a primary cause of the occupational level of the mining accident (in the case study). To train perception, we specific complementary activities such as labyrinths. Labyrinths are games that have mechanics such as moving and avoiding. The cognitive function of perception requires training to generate the capability to detect risks or hazards. It is necessary to measure the perception. Perception is measured by performing the psychological task of copying nine geometric figures. This psychological task is in the Bender cognitive test.

Cognitive functions control the characteristics produced by the emotion of fear. In this case, fear presents a disturbed state. The characteristics are arms, which take the parameter with the value crossed. The crossed arms are present in the behavior of staying still. A physical event called a methane gas explosion inside a mine produces this behavior. These characteristics or physiological changes are detected using recognition methods such as body language, as shown in **¡Error! No se encuentra el origen de la referencia.**.

Table 3. Graphical notation of the cognitive-affective model´s specification

Graphical Notation of the Cognitive-Affective Model					
Component	**Graphical representation**	**Component**	**Graphical representation**	**Component**	**Graphical representation**
Cognitive Function		Mechanic		Characteristic	
FunctionType		CognitiveTest		Parameter	
Level		Application		Behaviour	
Capability		TestType		Event	
PsychologicalTask		Emotion		Recognition Method	
Complementary Activity		State		EmotionType	

In **¡Error! No se encuentra el origen de la referencia.** 3, we present the graphic notation defined to denote each component of the cognitive-affective model and facilitate the understanding of the model's specification.

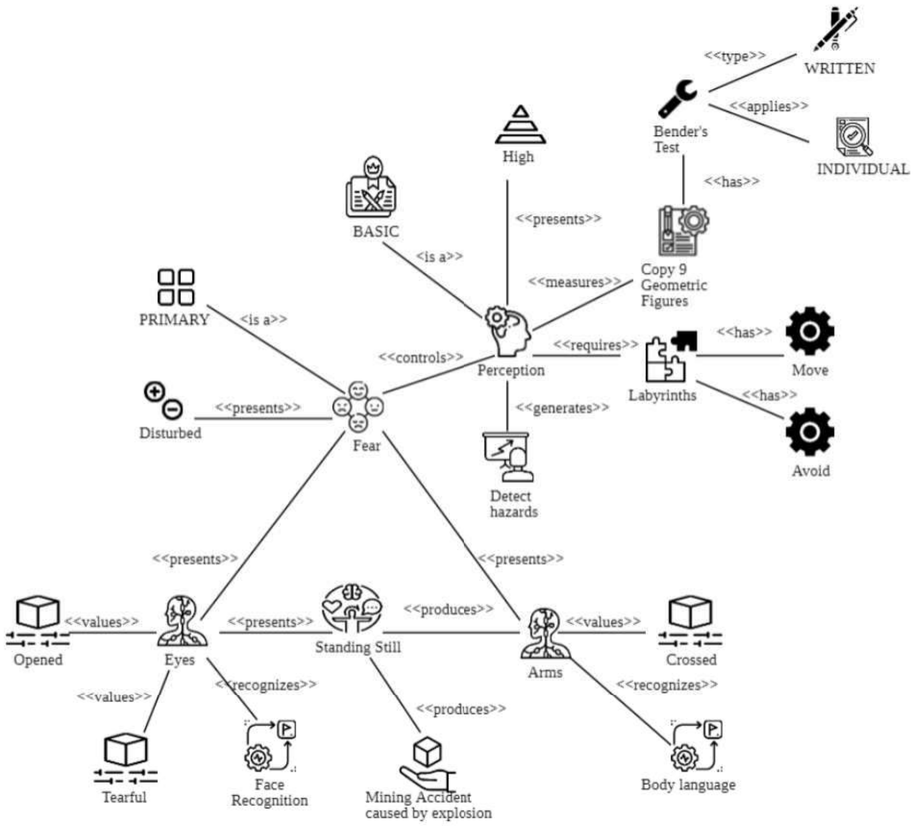


Figure 5. Cognitive and affective dimension specification

4.3 Example of a serious game: Virtual simulation of a gas explosion inside a coal mine

Based on our proposal of cognitive and affective dimensions, we developed the following example of a simulation of a gas explosion inside a coal mine in which the components of the cognitive-affective model are exemplified. The development of this example begins by reviewing the complementary activities defined in the specification of the cognitive-affective dimensions of the model (Figure 5), which in this case are the labyrinths. The labyrinths are used as the basis for the development of a virtual tour of a coal mine. And the mechanics specified in Figure 5 are considered in the gameplay of the virtual tour. However, the designer can include other mechanics that allow a better gameplay and engagement with the player.

In this way, the specification provides a starting point for anyone interested in designing serious games for affective cognitive training. The specification of the complementary activities that allow the cognitive training of the user induce in the creation of a virtual tour of the interior of a coal mine. Figure 5 shows that some complementary activities to train the cognitive function of perception can be labyrinths. In this case, we decided with the work team to design a kind of labyrinth that simulates the interior of a coal mine. We chose labyrinths for simplicity and ease of implementation (this depends on the development team's experience) since reproducing complex geometric figures may be viable for another development team.

The simulation is a virtual tour inside a coal mine **(Complementary Activity Component).** This virtual tour presents basic game *mechanics* such as moving inside the mine and avoiding danger **(mechanic component).** However, other mechanics such as grabbing coal blocks and dropping blocks were designed to give it a realistic gameplay. The virtual simulation of the interior of a mine allows the player to train perception **(Cognitive Function Component)** to generate the ability to detect hazards and respond quickly **(Capability Component).** When the player starts to load the wagon with coal blocks, a burst or explosion of gas **(Event component)** occurs. This explosion should produce a behavior **(Behaviour component)** in the player accompanied by certain physiological characteristics **(Characteristic component).** These characteristics are present in the emotion **(emotion component)** that the player experiences in the virtual world.

The virtual tour is a serious game developed with virtual reality technology and the Unreal videogame development engine. The game *genre* is role-playing; the player is guided by an instructor or game director, who gives instructions and explains the situations that will arise inside the coal mine. The *storyline* of the game starts as follows: the miner (player) enters the virtual world and find a coal mine, as shown in Figure 6a. To enter the mine, the player must use the control handle to locate the point where he/she wishes to position him/herself, as shown in Figure 6b.

Figure 6a. Visualization of the mine entrance

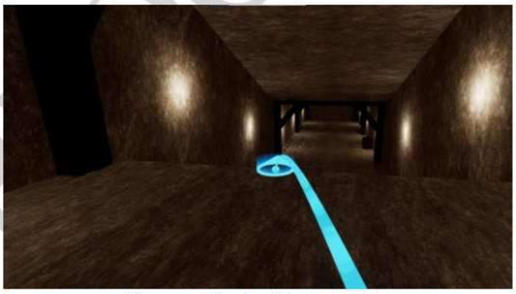


Figure 6b. Inside the mine

While the player moves along the virtual tour, he/she can observe the mine as a tunnel supported by wood and with low lighting. In this virtual tour, the player can manipulate *elements* such as coal blocks, as shown in Figure 7a. The game's *dynamics* is for the player to grab the blocks and place them in the wagon.

Figure 7a. Displacement of coal to the wagon

Figure 7b. Fire scenario generated by the gas explosion inside the mine

When the player begins to fill the wagon with coal, an explosion occurs, which generates some behavior in the player. According to the cognitive experience of the player, some gestures, movements, or verbal expressions will be observed in the player. These physiological changes depend on the feeling or emotions caused by the situation presented. The player must again look for the entrance and escape from the fire and smoke caused by the explosion. In this part of the game, a neurocognitive expert can evaluate the reaction capacity to a dangerous situation such as fire and smoke inside the mine. If the player stands still in front of the fire and smoke scenario in the virtualized mine, the instructor must guide the player to look for the exit of the mine without letting the smoke trap the player and cause him to lose visibility inside the mine. Figure 7b shows the smoke and fire scenario generated by the gas explosion inside the mine.

If, in the virtual tour, the player stands still, letting the fire grow and the smoke cover him, and does not look for help to get out. We face a user or player with a low capacity to respond to dangerous situations. In addition, we can conclude that the user is not trained in self-care or self-rescue. Therefore, the user needs to perform more training or cognitive stimulation. A cognitive expert evaluates this training through a **cognitive test** that measures the cognitive function **level** necessary to save his life in the virtual world. If the player saves his life in the virtual world, he will have a higher probability of saving his life in the real world.

If the player achieves to get out of the mine and flees from danger (smoke and fire inside the mine), the player is a user that responds quickly to dangerous situations.

The simulation has a restart option, allowing that the user to perform many training sessions in the virtual mine. The restart option in the simulation consists of deactivating the fire and smoke so that the player can enter the mine and to practices many times.

With the example of the serious game "Virtual simulation of a gas explosion inside a coal mine" of the case study of this article, we demonstrate that our research allows 1) The partial specification of a serious game to achieve cognitive training of the user. 2) A mechanism to evaluate the user's emotional behavior in risky situations. And 3) Safe and guided training in risky situations. Finally, the application of the serious game reveals the emotions experienced by each user from the moment he/she enters the mine in a simulated environment. Also, we could perceive the user's behavior before the simulated explosion, physiological changes (gestures and movements), and tone of voice.

5 Conclusions

In conclusion, with our work, we achieved: 1) To develop a mechanism for training or stimulation of cognitive functions through serious games. 2) To design the affective dimension to know the user's behavior in the face of occupational hazards and risks. And 3) to exemplify through a serious virtual simulation game for safe training in risk situations based on the proposed cognitive and affective dimensions.

The mechanism of specification of cognitive functions and emotions promotes their improvement using serious games. It is the result of the background review, from which we conclude that the works related to our research do not specify cognitive functions and emotions for improving training processes. With the specification of cognitive functions, we train the user through some components, such as complementary activities and game mechanics, that allow the generation of certain capabilities. With the cognitive dimension, we also propose a way to measure the cognitive level of the user before training with serious games. This cognitive measurement is done through cognitive tests and specific psychological tasks for each cognitive function; these tests are designed and applied by expert professionals.

With the proposed affective dimension, an instructor can recognize the emotions of the user's behavior in a risky event or situation. In the future, we seek not only to identify emotions. Also, we will evaluate in an automated way the cognitive level and the emotional state of the player using serious games. The affective dimension focuses on two-dimensional states, allowing the research community to propose work based on three-dimensional spaces to evaluate with greater scope.

We validate the research with a case study and an exemplification of the components of each dimension. This example corresponds to a serious virtual simulation game of a coal mine developed with the Unreal engine. The example allowed us to conclude that the accompaniment of a neurocognitive expert in cognitive and emotional training with serious games is necessary. Furthermore, this neurocognitive expert is required for the application of the cognitive and emotional evaluation of the user before, during, and after the training. Likewise, we conclude that it is necessary to automate the cognitive tests classified according to the cognitive function to be evaluated, supported by psychometric characterizations made by scientific experts.

Although in the future, we will automate the components of the cognitive and affective dimensions of the proposed model. We should follow the participatory focus of the iPLUS methodology for the two layers, i.e., we should include experts in cognition and emotion to analyze and measure the effectiveness of serious games in the training process.

In the following, we present some future work resulting from our research.

- Software design patterns linked to cognitive and affective models for the automation of model components.
- Formalization of the cognitive and affective dimensions proposed in this research using model-driven engineering.
- Characterization of gamification to develop serious games, specifically in the mining field.

Finally, we provide a mechanism that allows the specification of serious games for the training of cognitive functions and emotions present in the user in a specific event or situation. This specification was given thanks to the contributions of scientific experts in fields such as cognition (cognitive functions), emotions, affective computing, methodologies for developing serious games, and gamification (learning mechanics).

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