On the Development of Strategic Games based on a Semiotic Analysis: A Case Study of an Optimized Tic-Tac-Toe

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Abstract: A picture can express something instead of having a thousand words that cannot do it. This phrase, which symbolically connotes a whole scheme of a signs system, is known as Semiotics. This paper presents the process of an educational video game development based on semiotic analysis. We used Extreme Programing Agile Methodology combined with a proposal of the modified Elemental Tetrad Game Design Model to develop a video game known as "Tic-Tac-Toe". The mathematical model was implemented with Artificial Intelligence algorithms and a graphical user interface including Semiotics; this was optimized for producing an enjoyable and interactive environment. With the purpose of stimulating cognitive development of children, this research combines theories about stimulating cognitive development of children; game design model, Semiotic Analysis harnesses the Model of Aleferenko, and uses algorithms based on heuristics and numerical methods in client-server architecture. The concept was tested with a representative sample of seven to eleven years old children. The results demonstrated that educational video games with Semiotics stimulate the cognitive development of children.

1 INTRODUCTION

Aware of the importance of psychomotor activity and its impact on stimulating thought; teachers and early childhood specialists value motor activities and games. One of the most fundamental resources available for educators is educational video games. Therefore, researchers are permanently exploring new learning strategies to encourage children through educational video games. Nowadays, semiotic domains are emerging more notably and potentially, could make the videogame more attractive for children. One example of this is the customisation of the avatar in the first-person-shooter video games (Gee, 2008).

Visualization is better than verbal description; this phrase symbolically connotes a whole system of signs. Its analysis or decoding is called Semiotics. According to the Oxford Advanced Learner's Dictionary, Semiotic is "a general philosophical theory of signs and symbols that deals especially with their function in both artificially constructed and natural languages and comprises syntactic, semantics, and pragmatics". It studies the phenomena and objects of significance, sign systems, and the process of senses production (Halliday, 1978).

The connection between educational video games and semiotics has been studied for three decades. The study of Myers (1991) discusses symbols within computer games and how those symbols are transformed during play. Thorne et al. (2012) describe an exploratory study of the massively multiplayer online games with a complex form of semiotic ecologies. Huber (2013) addresses the problem by proposing a model for the interpretation of videogames based on the semiotic theory of Charles S. Peirce. Ruiz et al. (2014) used videogames to help High School students to improve their understanding of numerical evaluation of algebraic expressions. Baceviciute et al. (2014) explain the convergence and hybridization process between cognitive sciences, computer science and Artificial Intelligence (AI). Kendall, 2015 analyses serious games and Semiotics separately. Those studies claim for an integration of semiotic and artificial intelligence in video games.

The present study developed a process of an educational video game based on semiotic analysis; and tested the hypothesis of an application of

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Semiotics in the Tic-Tac-Toe videogame improves the motivation of the childhood senses and stimulates their cognitive development.

We have used the Extreme Programing Agile Methodology (XP) combined with the Elemental Tetrad Game Design Model, in order to ensure the quality of the software using Artificial Intelligence techniques in client-server architecture. The video game that has been developed and optimized is called Tic-Tac-Toe. The concept has been tested with a representative sample of seven to eleven years old children at an elementary school.

The key contributions of this study are: (1) two prototypes software developed for the Tic-Tac-Toe game, one with Semiotics; (2) a class library implemented that represents the environment and the rules of a third party using Artificial Intelligence based on heuristics and numerical methods; and (3) a game developed combining a novel mathematical model and semiotic analysis that requires algorithms of Software Engineering to optimize the Tic-Tac-Toe's ability to apply learning theories.

2 THEORETICAL FRAMEWORK

2.1 The Elemental Tetrad Game Design Model

This model is currently used for game design. According to Gibson (2014), this model uses the events of the story and states purpose of the game. It evaluates the human-computer interaction by using the game technologies. Furthermore, it separates the basic elements of a game into four sections: (1) Mechanics: the rules for interaction between the player and the game; (2) Aesthetics: describe how the game is perceived by the five senses; (3) Technology: this element covers all the underlying technology that makes the game work; (4) Story: this describes the sequence of events in the game.

2.2 Extreme Programming (XP)

XP is an agile software development methodology. It is a lightweight methodology using a set of existing software development practices in conjunction (Schneider, 2003). According to Beck (2000), the project lifecycle of XP includes the following phases: Exploration, Planning, Iterations to Release, the Product ionizing, and Maintenance. The practices taken from XP focused on software coding needed for the game.

2.3 Semiotic Analysis of Aleferenko

This model integrates several areas of the knowledge, and allows making a connotative and denotative analysis of the symbols. For Aleferenko (Tokarev, 2014) a pyramid constitutes the coalition of the Pierce's triad. It includes two new elements: Meaning/ Connotation; and Significant/ Denotation. This allows to create a pyramid organized with the following elements: (1) Sign; (2) Object/Referent; (3) Significant/ Denotation; (4) Meaning/Connotation; and Concept. The pyramid of Aleferenko integrates the bases of Semiotics. In contrast to Pierce and Frege (Wisse, 2002), Aleferenko considers outlined models and creates a new complete model, where the connotation is the agent of analysis that engenders a deep knowledge that leaves an appropriation of the receiver.

2.4 Theories to Stimulate Cognitive Development of Children

Tic-Tac-Toe stimulates cognition of children, and the game is part of the culture as it is included in common educational practices. Lev Vygotsky (1967) assigned the game into the category of instrument and socio-cultural promoter of children's mental development, and the results showed that facilitates the development of higher functions. These are acquired through interaction with the surrounding world. The approach of mediation according to Vygotsky is perceived as the presence of people, objects, and situations that interact in various socio-cultural contexts, which can be verbal, visual and physical, and can generate experiences that affect cognitive development. Vygotsky elaborated the concept known as Zone of Proximal Development Theory (Brown, 1999), explained as: (1) the distance between the actual developmental level is determined by the ability to independently solve a problem; and, (2) the level of potential development is determined by problem solving under the mediation of an adult.

Feuerstein (1991) considers that the subject's interactions with the environment can have two modalities: (1) direct exposure to stimuli; and, (2) learning experiences through mediators. As suggested by Feuerstein, it is crucial to consider that all human beings are modifiable. To be able to fulfil this condition, we should understand mediation as an intervention strategy that tries to affect the body of mediator, seeking greater efficiency in the process of information and therefore the cognitive structure. Finally, Lipman (2002), developed his educational philosophical proposal known as "critical thinking",

that is interested in forming a thought careful, orderly, prudent and reasonable. In this sense the children are be able to make judgments as part of the practice of their own learning process in which case an educational game is considered like a learning activity.

All these theoretical assumptions analysed converge in cognitive modifiability through the visual mediation using games. We conclude therefore, that children exposed to the complexity experience of the games, shows increased cognitive skills such as spatial navigation, reasoning, memory and three dimensional perceptions.

3 EXPERIMENTAL SETUP

3.1 Development Process

The process of development of the video game with Semiotics was based on the life cycle of XP that performs iterative and incremental tasks (Beck, 2000), (Schneider, 2003). The research team carried out an incremental delivery of the product in each iteration.

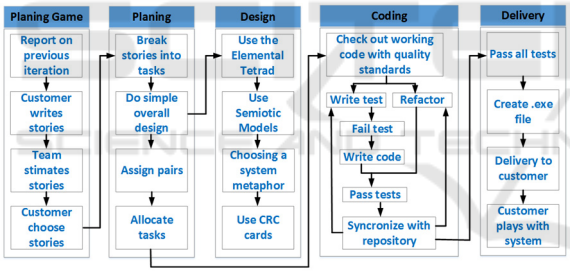

Figure 1: The Extreme Programming iterations game.

The experiment considered three iterations: (1) The design and development of the graphic user interfaces of the video game, for which we applied elementary Tetrad Game Design modified Model; (2) The construction of the inference engine, based in technical heuristics of Artificial Intelligence implemented with numerical methods that generate different levels of difficulty in the game; (3) The processing and storage of information, that keeps the users scores in files, considering the three levels of difficulty. In these iterations, liberated parts of the product were inspected and evaluated to increase the functionality and also to improve the quality compared to the previous versions of the game (Villacís, 2015), which has been implemented without using Semiotics. Fig. 1 shown the XP iterations game model modified based in the proposed model by Drake et al. (2006).

3.2 Design and Development of the GUI

The design and the development of the graphic user interface of the Tic-Tac-Toe video game were based on the Elementary Tetrad Game Design Model (Schell, 2014). For each one of the four sections of this model, we considered a series of elements related to programming computer games proposed by Walnum (2001), among them are: (1) Game design; (2) Graphic design; (3) Controls and interfaces; (4) Generation of sound; (5) Image handling; (6) Animation; (7) Algorithms; (8) Artificial Intelligence; (9) Game Testing. Additionally, it was necessary to include the Storyboard proposed by Páez (2013). Based on all of these elements, we propose the modified model illustrated in Fig. 2. The Mechanics section includes game algorithms and Artificial Intelligence algorithms. The Technology section includes graphic design, animation and image handling. The Aesthetics section includes control and interfaces, sound generation and game testing. The story section includes game design and storyboard.

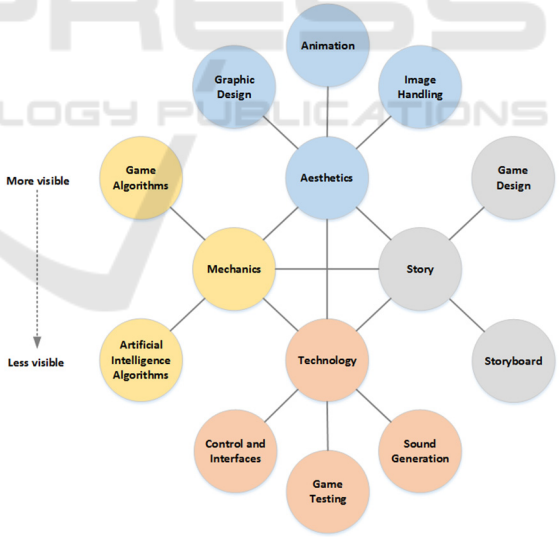

Figure 2: A proposal of the modified Elemental Tetrad Game Design Model for this study.

3.2.1 Game Design

The concept was based on real-world events related to the design and creation of boards for the game of Tic-Tac-Toe. This is a fun game that appeals to both children and adults because it is a game of strategy.

3.2.2 Graphic Design

The game screen of Tic-Tac-Toe has a form programmed in C# .NET, which is very similar to the dialogue frames of the Windows System. In this form is placed a series of objects that allowed to structure the game, such as: (1) Nine buttons for checkers, mathematically located in specific locations; (2) Four buttons to manage the game options (i.e. New, Choose players, Choose language and Exit); (3) Four group boxes or containers (Group Box); (4) One label for static text; (5) Four radio buttons to control the different levels of the game; (6) One picture box, which shows an animated icon; (7) A menu bar with File, Help and View options, and their respective submenus.

3.2.3 Control and Interfaces Implementation

The GUI was constructed based on components (COM+), and basic controls (ActiveX) that provided the Visual C# .NET programming language. The scores in the game were stored in XML flat files, and the data are displayed within the Data Grid View control. Fig. 3 illustrates the GUI of the game:

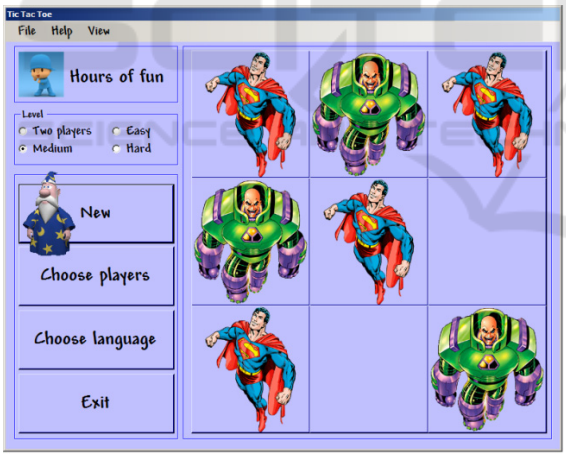

Figure 3: Graphical User Interface of the Tic-Tac-toe game using Semiotics.

3.2.4 Image Handling

We organized all the visual interfaces to handle images via ActiveX controls. For example, the Picture Box control allows loading animated gif files and the Button control is designed and constructed with geometric shapes which can load images in various formats. We have defined four categories in the game related to the nine buttons of the board, which are available for the user being: (1) *Super hero*: Selection between twelve super heroes and twelve villains; (2) *Princesses*: Selection between twelve princesses of fairy tales and twelve villains of those same fairy tales; (3) *Animals*: Selection between twenty four animals among which are both wild and domestic animals; (4) *Miscellany characters*: Selection between several well-known children's characters with their respective antagonistic characters. Finally no special background (i.e. Background Image property) was included, only colours, which is more attractive to children and generates much less distraction.

3.2.5 Sound Generation

Because the real world is a place with sound, the game needs to include sound so that it seems realistic. The Tic-Tac-Toe game is not the exception. Therefore, MIDI sounds type was implemented using Windows Media Player control.

3.2.6 Animation

A virtual assistant and speech recognition libraries for both: Spanish and English language were implemented using MS Agents by Microsoft.

3.2.7 Game Algorithms

One of the most important algorithms in the game is the algorithm that allows two users to play each other on the same computer or a user to play against the computer with AI. Depending on the level that the user chooses for which the function Play() has been implemented inside the form frmTicTacToe whose algorithm is presented at the end of this subsection.

The parameters of the managed objects explained above are: (1) *board*: whose value depends on the category chosen by the user; (2) *btnTicTacToe*: whose value depends on which the button has been clicked by the user; (3) *type*: whose value depends on the fictitious good or bad character chosen by the user; (4) *player1*: whose value depends on the character, animal or object chosen by the user based of the type and the board; (5) *player2*: this parameter represents the non-player character (NPC) selected by the user for the confrontation; (6) *grbTicTacToe*: this control represents the container that hold the nine buttons and when the game is over this control disables these buttons; (7) *dgvData*: this control shows the final results of the players saved on XML files; (8) *listButtons*: this parameter is used exclusively by the non-player character (NPC) in which case the button is selected depends on the heuristics techniques of Artificial Intelligence.

3.2.8 Artificial Intelligence Algorithms

Within the context of this study, the Artificial Intelligence algorithms focuses on providing capacity to computers to perform tasks that require human intelligence. This means, the ability of the computer to act or participate as an opponent in the game (Walnum, 2001). In the Tic-Tac-Toe game, the computer has the ability to play with the user, according to three different levels of difficulty: basic level, intermediate level, and advanced level. For the Artificial Intelligence model of the application we have used both weak and strong heuristics techniques. Here we use numeric method based on numeric series that is represented by linked lists and arrays. These kind of structures store different movements made by the same application that is the non-player character (NPC) controlled by the computer that plays with the user. The numeric method based on finite series is indicated in Table 1, where each finite series has been obtained based on a sum that represents a value accumulated in a certain row, column or diagonal of the Tic-Tac-Toe game. In Table 2, the initial state of the whole array is depicted (i.e., that is zero) and it corresponds to an empty space or a free cell. Some cases are described below:

Table 1: Numeric method based on finite series.

Rows	$\sum_{i=0}^{n=2} f_i = a$	$\sum_{i=3}^{n=5} f_i = b$	$\sum_{i=6}^{n=8} f_i = c$
Columns	$\sum_{i=0}^{n=6} c_i = d$ Step 3	$\sum_{i=1}^{n=7} c_i = e$ Step 3	$\sum_{i=2}^{n=8} c_i = f$ Step 3
Diagonals	$\sum_{i=0}^{n=8} d_i = g$ Step 4	$\sum_{i=2}^{n=6} d_i = h$ Step 2	
Diagonals (Trivial Case)	$\sum_{i=0}^{n=8} d_i = x$ Step 4	$\sum_{i=2}^{n=6} d_i = y$ Step 2	
Edges (Trivial Case)	$\sum_{i=2}^{n=5} t_i = p$ Step 3	$\sum_{i=1}^{n=3} t_i = q$ Step 2	
	$\sum_{i=5}^{n=7} t_i = r$ Step 2	$\sum_{i=3}^{n=7} t_i = s$ Step 4	

- **Case 1:** The non-player character (NPC) obstructs the user. In this case the following instruction should be considered: if ((a = 2) ∨ (b = 2) ∨ (c = 2) ∨ (d = 2) ∨ (e = 2) ∨ (f = 2) ∨ (g = 2) ∨ (h = 2)) then: if (v[k] = 0) then v[k]:= 3 → NPC obstructs the user;
- **Case 2:** The non-player character (NPC) wins. In this case the following instruction should be considered: if ((a = 6) ∨ (b = 6) ∨ (c = 6) ∨ (d = 6) ∨ (e = 6) ∨ (f = 6) ∨ (g = 6) ∨ (h = 6)) then: if (v[k] = 0) then v[k]:= 3 → NPC beats the user;
- **Case 3:** Obstruct in the diagonals. In this case the following instruction should be considered: if ((x = 5) ∨ (y = 5)) then: if (v[k] = 0) then v[k]:= 3 → NPC obstructs the user;
- **Case 4:** Obstruct in the corner squares. In this case the following instruction should be considered: if (((p = 2) ∨ (q = 2) ∨ (r = 2) ∨ (s = 2)) ∧ (v[k] = 0)), where k = 0, 2, 6, 8; then: if (v[k] = 0) then v[k]:= 3 → NPC obstructs the user in the corners close to the edges occupied by the user.

Table 2: Finite State Machine of the Game.

Object	Weight
User 1	1
Non-player character (NPC)	3
Blank space	0

3.2.9 Semiotic Model of the Game

Figure 4 shows the model of Aleferenko (Tokarev, 2014) which completes: K=S+O+D+C; where K is the Concept, S is the Sign, O it is the object, D it is the denotation and C it is the connotation. This model demonstrates the real state of the construction of the knowledge on the receiver's part since it is unable to jump the denotation and connotation process to arrive at the concept.

In the first instance, the sign is the word that corresponds to the game. In our case the sign begins the code process to obtain knowledge. In the second instance, the object referent corresponds to the code of the game. In the third instance, the receiver passes to the connotative process where it identifies the signs as symbols. Therefore it is not an arbitrary process of significance. The connotation process is in the fourth instance, where the receivers are the children that play the game, in an appropriate atmosphere. Also, according to their preferences, the sign that doesn't has the character of arbitrary in this case because they become symbols. For instance, in the case of the Superman – sign (the symbol of a super hero), which would correspond to K that is the concept of the sign S, and in similar form is Lex Luthor – sign (the antagonistic or villainous symbol with respect to superman). Finally, the result is the concept or knowledge decoded due to the process of connotation of the sign.

3.2.10 Principle of Arbitrariness of the Sign

According to Holdcroft (1991), the principle of arbitrariness of the sign consists in the bond among the meaning with the significance of arbitrary. This, since the sign is equivalent to the association of a significant with a meaning. For this reason the game of the Tic-Tac-Toe is decoded like it was mentioned previously, being a matrix with two elements: a 'cero' and an 'x' letter, generally constructed in paper or with wood. The concept or significance of Tic-tac-Toe is not bound for any relationship with the sequence of sounds "t-i-c-t-a-c-t-o-e" that serves by itself significance to the word. It could be represented by any other sequence of sounds, for example the "Tic-Tac-Toe" game in English corresponds to "Tres en Raya" in Spanish and in Russian, it corresponds to "крестики-нолики", where it doesn't only change the sound but even the system of signs that doesn't correspond to the Latin alphabet, and the system corresponds to the Cyrillic one instead.

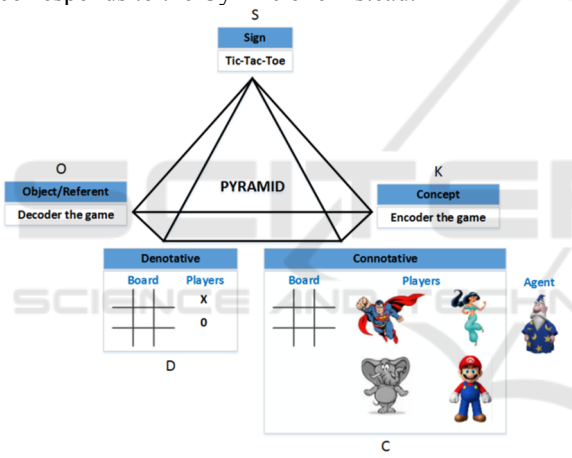

Figure 4: The semiotic model Aleferenko for the game.

3.2.11 Testing the Game

We applied the game to a public school, forty seven to eleven years old children were randomly chosen to play the game during 30 minutes. A group of children were exposed to the traditional Tic-Tac-Toe game (i.e. without Semiotics) versus the optimized Tic-Tac-Toe game (with Semiotics). After, the children tested the game, we proceeded to perform statistical processing of the scores provided by the game. As noted in this study, it has been optimized as the Tic-Tac-Toe game, incorporating the semiotic model of Aleferenko. This research has involved superheroes, princesses, other animals and world comics.

4 EVALUATION RESULTS AND DISCUSSION

4.1 Results of the Evaluation

There were differences of comic figures preferences. Fig. 5 illustrates that there is a superhero that has the popularity of 100% (i.e. Hulk), followed by another one with 81.8% (i.e. Spiderman). The other two with 36.4% (i.e. Superman), and Wonder Woman with 27.3%. Batman and Green Arrow with 18.2% and 9.1%, respectively. This means that two superheroes were known to more than half of the children with more than 50% of the total popularity, while 14 other superheroes yielded amounts between 18.2% and 36.4% on average, and just six below 9.1%. This leads to the conclusion that 16 boys were interested in recreational games with superheroes.

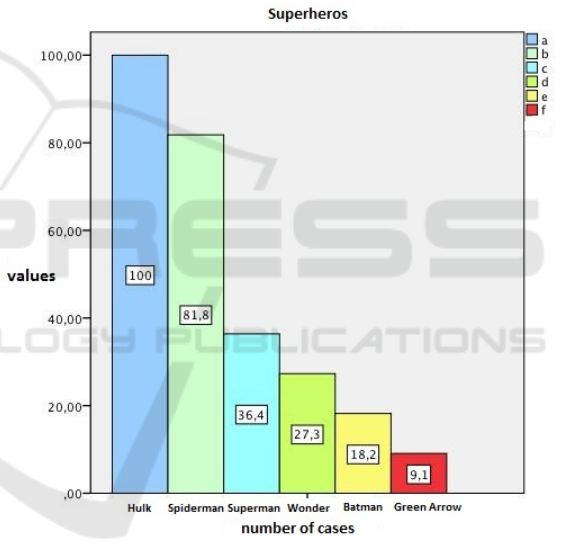

Figure 5: Bar chart of the most popularly superheroes selected in the game.

In the case of girls the results were: Two princesses reached total popularity of 100% (i.e. Anna and Elsa), while five reached popularity amounts between 16.7% and 41.7% (i.e. Rapunzel, Ariel, Goethel, Jasmine, and, Cinderella). These amounts are all above average. However 17 are almost unknown to the children as they reached popularity values below 8.3% (Snow White, Pocahontas, Queen Grim Hilde, Shan Yu, Hans, Bella, Mulan, Tiana, Merida, Aurora, Lady Tremaine, Ursula, Jafar, John Ratcliffe, Dr Facilier, Queen Elinor, and Maleficent).

The results accomplished by children in the fifth grade of elementary school at the intermediate level

shows that the modified Tic-Tac-Toe game (with semiotics) conducted the successful challenge by the children., but gender difference were detected. Fig. 6 illustrates that in the normal game did not crystallize any winners, but there were three losses and three ties (i.e. equal finish). The girls in turn drew all. On the other hand, Fig. 7 demonstrates two boys won, having just three losses and one draw. Girls continue getting the same draws. However, in the case of girls no improvement could be reached. This analysis was performed in each grade and with different levels (i.e. basic, intermediate and advanced) demonstrating better results with the game optimized with Semiotics, contrasting the research hypothesis convincingly.

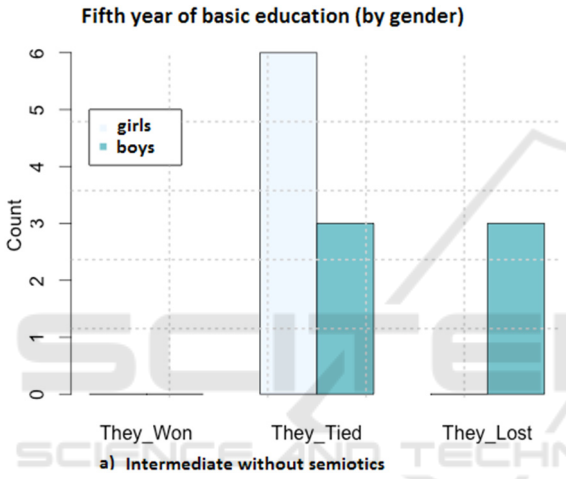

Figure 6: Results obtained using Tic-Tac-Toe game without semiotics.

Finally, the illustration in Fig. 8 has been obtained by the means of the method of Natural and Hyman. In this figure it is demonstrated, that the frequency curve of the normal variable change fairly its tendency compared to the curve generated by the semiotic variable. This leads to the conclusion, of the existence of a greater homogeneity of the data of the semiotics variable compared with normal variable. Thus, we are able to suggest, that it is more difficult to resolve recreational games with normal conditions when a semiotic modelling applies. Therefore, we deduce that semiotics grows proportionally affecting more positively the learning in an objective and scientific way. Similarly, based on the study conducted at different grades (second to sixth grade) in an elementary school we obtained a similar behaviour.

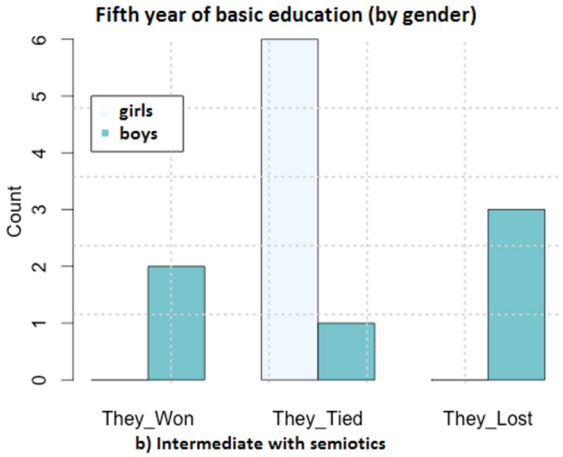

Figure 7: Results obtained using Tic-Tac-Toe game with semiotics.

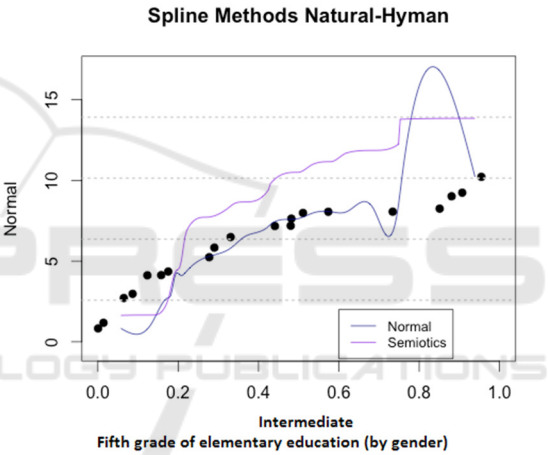

Figure 8: Results obtained adjusting an algebraic polynomial from the absolute cumulative frequencies.

4.2 Discussion

It is considered that the Aleferenko model integrates the foundations of Semiotics. Another important fact that carried this model to the desktop platform game is its friendly appearance. Therefore, it has been empowering for the comprehensive knowledge of children between 7 and 11 years old and can be used as part of the teaching-learning process of schoolchildren, because this game is a strategy educational game that is using to stimulate logical and spatial reasoning. In this study, that was achieved due to the implication of connotative analysis in deep through Artificial Intelligence and Software Engineering, which causes the receiver (user) uses tactics and strategies to beat the computer. Thus, a dynamic environment was created in the game for the

receivers who can have their own signs according to the age. They lose their arbitrariness and the symbols become the identifiers with which the children are related and can create relevance and internalization of the knowledge, and above all to create interactivity. Another important aspect when evaluating the game includes the use of signs and symbols and their diagnostic meaning for the children. Therefore, this creates a natural, interesting, efficient and motivating learning.

5 CONCLUSIONS

This research focused on how to optimize an educational video game named Tic-Tac-Toe by means of semiotics analysis, in order to stimulate logical and spatial reasoning of children. The main issue in our study has been to design a mathematical model, which is implemented with AI algorithms and a graphical user interface including Semiotics, applied to an incremental methodology with the aim of producing an enjoyable and interactive environment. To carry out this study, we have used the Extreme Programing (XP) agile methodology for the codification and testing of the incremental products in each iteration (sprint), combined with the modified Elemental Tetrad Game Design Model for defining the performance of the game's models, in order to ensure the quality of the software used. To validate our results, the proof of concept and testing has been performed with a representative sample at an elementary school, focused on children with ages ranging from seven to eleven years old. The results imply that educational video games with Semiotics stimulate cognitive development of children.

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