Chapter 11
Al-Kimia: How to Create a Video Game to Help High School Students Enjoy Chemistry

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Abstract This chapter describes the creation process of "Al-Kimia", a video game targeted at Spanish high school students that aims to generate positive attitudes towards Chemistry (and Science in general) amongst its players. It is hoped that this will provide a useful reference to guide the development of similar titles in the future.

Firstly, it explores the reasons why a video game was chosen as a resource to achieve educational objectives. Secondly, the effectiveness of game-based learning has been analysed, with references to the available literature.

One of the key sections of the chapter describes the process that was followed to define the structure of the video game. Hunicke's Triad (mechanics–dynamics–aesthetics), Schell's Elemental Tetrad (aesthetics–mechanics–technology–story) and Kiili's Experiential Gaming Model are theoretical frameworks that were reviewed. In order to meet the requirements of the project, a new hybrid framework for the design of educational video games was created.

A more detailed description of the project's development provides an example of how this theoretical framework was used in a real-world situation. The challenges that were faced by the team and the steps that were taken to overcome them are also described.

Finally, this chapter focuses on the research studies that have been designed to measure the impact of the game amongst its target audience, as well as the lessons learnt from the whole development process.

Keywords Custom-made game • Edutainment game for mobile devices • Game design process for educational games • Role-playing game • Action game • Graphical adventure • High school • Secondary education • Chemistry • Science

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11.1 What Is Al-Kimia?

"Al-Kimia" is a combination of role-playing + action + graphical adventure title that includes simulation elements (tests, games) for mobile devices[1]. Players get a chance to do real chemical experiments in a virtual world, acquiring real chemical knowledge in the process and understanding how these discoveries have had a real-world impact. This title aims to generate positive attitudes towards Chemistry (and Science in general) amongst its players.

"Al-Kimia" is a joint effort between the video game team of the Faculty of Social Sciences and Communication of the University of Vigo and members of the Faculty of Chemistry of the University of Santiago de Compostela. Both teams are based in Galicia, in the northwest of Spain. This project has received competitive funding from the Spanish Ministry of Economy and Competitiveness.

Traditional teaching methods in Spain approach Chemistry (and other scientific subjects, for that matter) in a dry and unengaging manner. This creates a barrier to entry that limits the appeal of Chemistry as a viable option for further study and professional development. In other words, Chemistry remains a relatively unknown subject, which is not highly valued within the general student population. Aware of this reality, Chemistry teachers in the University of Santiago de Compostela were interested in changing this negative perception but discovered a lack of resources aimed at presenting chemical concepts in an entertaining and engaging manner. Overcoming this lack of resources provided the starting point for "Al-Kimia". Its development has been guided by the constructivist theory of experiential learning.

11.2 Why Design a Video Game About Chemistry?

Video game players are normally considered to be male teenagers, but is this stereotype actually true?

According to the Spanish Video game Association (AEVI 2015), in 2014, there were 14 million video game players in Spain, 40% of the total population. Spain is the fourth largest video game market in Europe by number of players, behind France, Germany and the United Kingdom. Spanish gamers between 11 and 64 years of age spend an average of almost 6 h per week playing. Over 77% of 11–14-year-olds play video games, compared to 75% of 6–10-year-olds, 66% of 15–24-year-olds, 48% of 25–34-year-olds, 35% of 35–44-year-olds and 15% of 45–64-year-olds. Spanish women account for 46% of total gamers, compared to 44% in the United Kingdom.

In 2014, total revenues for the Spanish video game sector were 996 million euro; packaged games accounted for 755 million euro, whilst online games generated 241 million euro (AEVI 2015). The video game industry has consolidated its position as the leading form of audiovisual and interactive leisure in Spain.

[1] An Android version of the game can be downloaded from https://alkimiasite.wordpress.com/. The game will also be available in the Google Play and in the Apple Store.

Analysis of this data suggested that a video game could be an effective platform for reaching high school students and to have them engage with Chemistry in a different way. The next steps were to discover how video games could be used as learning tools, choosing the type of video game, defining the elements it should contain and, finally, how to adapt the basic scientific knowledge to create an engaging game.

11.3 Use of Games as an Effective Learning Tool

Students' interest in digital technologies would suggest that including them in the classroom could be an effective way of facilitating learning and engagement. But it's important to highlight that just using digital technology does not guarantee this; a deeper change in the teaching process is needed whereby the teacher's role evolves from being a "speaker" to becoming a guide and enabler of experiences.

One possible approach to using technology in the classroom can be the use of video games, as their use can help create a culture of learning that is better adapted to the interests of students (Prensky 2001 cited in Kiili 2005). In this case, games must motivate students through experiences created in the game world and, at the same time, offer them the chance to explore, develop hypotheses and build objects (Kiili 2005:14). On the other hand, video games enable students to discover new rules and ideas, rather than just memorising learning materials created by others, thus giving meaning to the concept of problem-based learning.

This way of learning connects with what has been called experiential learning. Dewey (1938 cited Chisholm et al. 2009) highlights the important role experiences have in the promotion of knowledge, as individuals learn when they find meaning in their interaction with their environment. Smith (2001 cited Romero Ariza 2010) claims that one of the defining characteristics of experiential learning is that it involves the individual in a direct interaction with that which is being studied, instead of merely contemplating or describing it. Esnaola (2009) suggests that the objective of school learning isn't that students memorize or understand content; they should be able to demonstrate their understanding by their actions, solving problems in increasingly complex contexts.

All of the above suggested that a video game could indeed be an effective resource to make students engage with a complex subject such as Chemistry.

11.4 What Type of Video Game Is Most Effective for Learning?

Not all video games are the same, so it is important to know which types are more suited to a learning-based scenario such as the one being discussed. As the video game industry has matured, it has begun to receive increasing attention from academia, giving rise to different types of video game classifications.

Games were initially classified based on the technical characteristics of the machines they were played on (i.e. 8-bit, 16-bit, 32-bit, etc.). They were later organised based on what players could do during the game, giving rise to genres such as action, fighting, platforms, role-playing and adventure games. As technology has evolved, new types of games have appeared, such as real-time strategy or massively multiplayer online games.

Different authors have recently focused on the subject of video game classification. Djaouti et al. (2007, 2008) suggest classifying video games based on their rules, having been inspired by the methodology that Vladimir Propp used to classify Russian fairy tales. Sánchez and Gómez (2014) prefer creating a unique and free taxonomy for video games, with no links to other media.

In the case of Al-Kimia, the concept of Game Gestalt seemed especially relevant. Defined by Craig Lindley (2003), Game Gestalt says that it's not necessary to know all the rules of a video game in order to play it, although some rules must have been consciously learnt; the key thing is to establish a pattern of interaction with the game system, so that it can be enjoyed without having to read complex instruction manuals.

Some of the types of games to which the concept of Game Gestalt can be applied are:

- Action games: shoot whilst being attacked, healing, repetitive actions.
- Role-playing games: assume the role of a character and develop it by completing different tests.
- Strategy games: organize armies, conquer domains and defeat enemies.

When designing Al-Kimia, it was important to define what players would have to do; where, how and when they would be able to do it; and what they would achieve by doing so.

Story was another important element that needed to be taken into account when designing the game. In this case, the challenge was to find a narrative structure that would allow the history of Chemistry to be told within the game.

Ever since Homer compiled ancient oral legends, almost everything can be classified as story or narrative. But in this case, we define narrative as an experience that's time-based, that has a protagonist that faces a conflict that must be resolved and which can change as the player makes choices between possible outcomes (Cassidy 2011:294). In other words, we are talking about an interactive fiction adventure.

In the case of Al-Kimia, it was considered important to be able to demonstrate some of the basic chemical processes in an explicit and clear way. To do this, the use of simulation became necessary. In this case, simulation is understood as "representing something or experimenting with a model that imitates certain aspects of reality" (Pérez Porto and Merino 2011).

In conclusion, in order to achieve the basic objective of Al-Kimia, it was decided that the game should be a combination of role-playing + action + graphical adventure title that included simulation elements (tests, games).

11.5 How to Design a Digital Game

Stereotypes exist about the design of video games in the same way as they exist about gamers themselves. It can be considered a technological activity, as it is computer-based; it can also be considered an artistic endeavour, because what appears on the screen is so important. But designing a video game is not an art; it is a craft, and, as such, it is necessary to know the tools that are used in the creation process.

When creating anything, it is important to know the different parts that will form it and how they will relate to each other. This is especially true when designing a video game: it must be technologically correct so that it works as expected; it must be visually attractive; it must be entertaining and playable; and, in the case of a title such as Al-Kimia, it must contain information that will stimulate learning.

Defining video games is outside the scope of this work and has already been addressed by authors such as Salen and Zimmerman (2003), Esposito (2005) and Frasca (2003), amongst others. The different approaches to video game research (ontological, methodological or field-based, as per Cardero et al. 2014) are also outside the scope of this paper and will not be addressed either. In the next pages, the focus will be on discovering and defining the different elements that form a video game.

Different researchers have attempted to define the structure of video games. In *Toward a Unified Theory of Digital Games*, Ralph and Monu (2015) argue that the main elements of a video game are technology, story and playability. Earlier, in "A Formal Approach to Game Design", Hunicke et al. (2004) suggested that the main components of games are mechanics, dynamics and aesthetics (see Fig. 11.1).

Mechanics are described as "the particular components of the game, at the level of data representation and algorithms". Dynamics describe "the run-time behaviour of the mechanics acting on player inputs and each other's outputs over time". Aesthetics describe "the desirable emotional responses evoked in the player, when she interacts with the game system" (Hunicke et al. 2004:2).

In the *Elemental Tetrad*, Schell (2008) defined aesthetics, mechanics, technology and story as the four basic components of a video game (see Fig. 11.2). In this case, Schell defines aesthetics as "how your game looks, sounds, smells, tastes and feels". Mechanics are "the procedures and rules" of the game. Technology refers to "any materials and interactions that make [the] game possible", whilst story is "the sequence of events that unfold in [the] game", either "linear and prescripted" or "branching and emergent".

Other authors have approached the theory of game design from the perspective of "serious games", which have been defined by Chen and Michael (2006) as "Games that do not have entertainment, enjoyment or fun as their primary purpose".

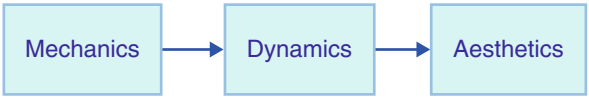

Fig. 11.1 Mechanics, dynamics and aesthetics (Hunicke et al. 2004)

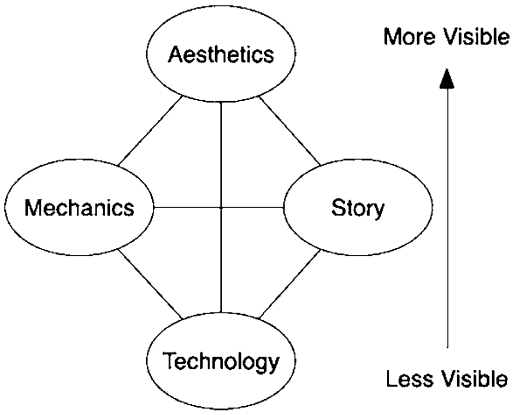

Fig. 11.2 Elements that form a game (Adapted from Schell 2008)

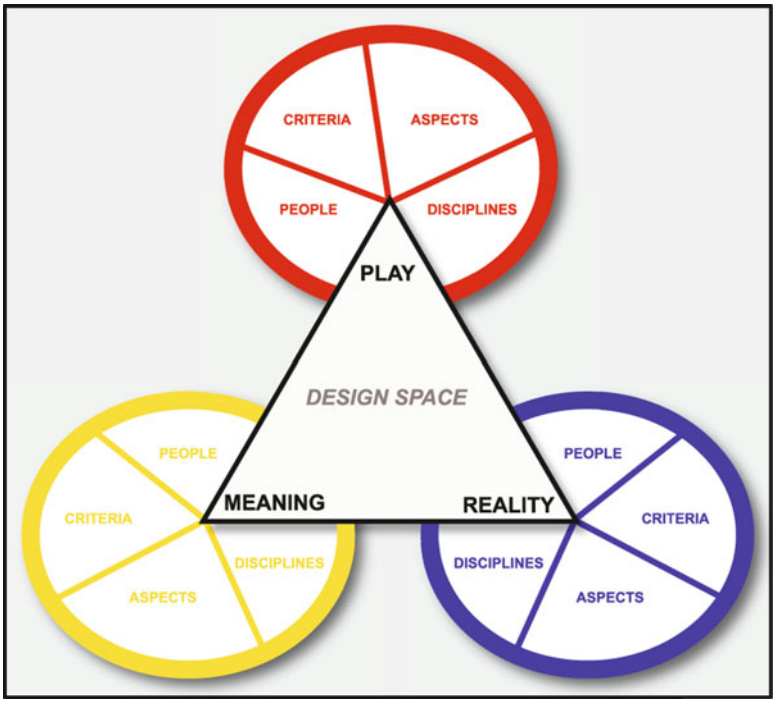

Fig. 11.3 Triadic game design (Harteveld 2011)

Harteveld (2011) has proposed the Triadic Game Design model, which considers three main aspects in the design of a video game. Meaning refers to how players interpret the game; reality is where the game takes places; and play refers to the game playing experience (see Fig. 11.3).

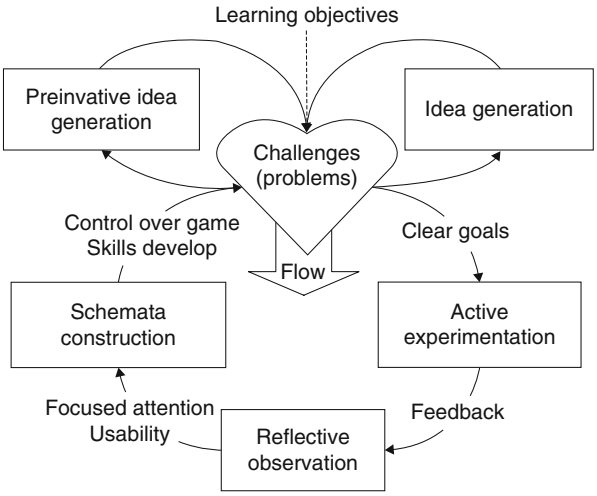

Fig. 11.4 The experiential gaming model (Kiili 2005)

In the *experiential gaming model*, when analysing the design of games in education, Kiili (2005) argues that games present challenges to players that can be considered learning acts (see Fig. 11.4).

When designing Al-Kimia, all of the above models were reviewed in order to identify the one that would be best suited for the project. After careful consideration, however, it was felt that no single model would fit all the needs of the project, so a hybrid approach was chosen. The Experiential Gaming Model proposed by Kiili was used to define the core of the game, but elements of both Hunicke's and Schell's approaches were also taken into account. By combining these models, both the gaming and learning objectives were aligned to create an attractive and entertaining video game that would communicate its learning objectives effectively.

Figure 11.5 represents the different elements that were used to design Al-Kimia, an educational role-playing + action + graphical adventure video game.

Within this new approach, *mechanics* are considered to be the processes and rules of the game (Schell) that will help define its *dynamics*, which can be defined as the behaviour of the player (Hunicke); *aesthetics* refer both to the way the game looks and sounds (Schell) and to the player's emotional response when interacting with the game (Hunicke), whilst the *story* (Schell) will focus on the subject matter to be learnt, in this case the history of Chemistry.

The elements of the experiential learning process proposed by Kiili can be linked to each of the elements defined above. The *learning objectives* are developed within the story; the *challenges (problems)* that the player must overcome are linked to the mechanics, so that the dynamics they inspire will allow *active experimentation* by the player; the combination of these elements will enable the *construction of schemas* that, via the game's aesthetics, will create a state of *flow* in the player that will ensure that a learning experience takes place.

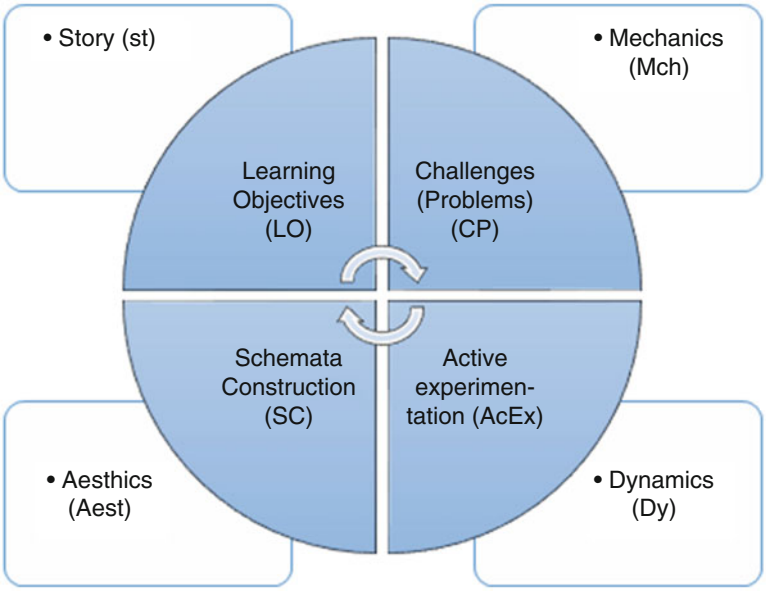

Fig. 11.5 Framework for the design of an educational video game (Role-playing + action + graphical adventure)

11.6 Al-Kimia

Al-Kimia is a combination role-playing + action + graphical adventure title that includes simulation elements (tests/games) for mobile devices (smartphones and tablets).

Role-playing In role-playing games, players assume the roles of characters in a fictional setting. They take responsibility for acting out these roles within a narrative.

Action In an action game, players must use their speed, skill and reaction times to achieve their objectives.

Adventure Game The main characteristic of this type of games is that they are based on a narrative; players assume the role of one of its protagonists, and they must resolve different tests to advance and reach the conclusion of the narrative, like in a book or a movie.

According to Dillon (2004), some of the key characteristics of adventure games are:

- Game play is primarily driven by a narrative through which the player moves as the game progresses.
- The player generally controls the main character.

- Games are often based around quests or puzzles, which are solved through interaction with the game world and its objects – this is often integral to the game experience.
- Emphasis is on exploration, thought and problem-solving abilities.

In other words, they are games that invite players to explore the settings and objects within the game, with interesting and attractive characters. They keep engagement levels high by balancing a good story with giving the player choices to interact with it. They stimulate comprehension, observation and memory.

Al-Kimia is a combination of all of the above. Players will have to discover information to fill in the blanks in a mystery narrative. They will have to interact with other characters that represent famous chemists across the ages, and they will have to make the most of different objects they will find as the game progresses. They will also have to overcome tests based on real chemical experiments and defeat different enemies as they acquire new skills.

When designing a video game, choosing the right platform and format is the key. In this case, both the target audience (high school students) and the objective (making Chemistry more attractive) were taken into account to choose mobile devices (smartphones and tablets) as the ideal platform for this title. Players are able to play whenever they want, wherever they are. By structuring the game in different levels and allowing players to save their progress along the way, players aren't required to make a significant commitment to the game. Using this casual gaming approach broadens the pool of potential players.

11.6.1 The Story

Enzo is a high school student that, after finding a blank ancient book amongst his great-uncle's belongings, is magically transported to different moments in time. He will have to perform different experiments, gaining basic chemical knowledge along the way. As he progresses through the game, his great-uncle's book will fill up with information about the main discoveries that have shaped Chemistry through the ages. But Enzo will also need to build up his other skills, as evil Zósimo and his gang will try to block his way and erase all scientific knowledge.

To achieve his objectives, Enzo will be able to use different items that will allow him to defend himself and to attack his enemies. Different mentors will guide him along the way, including Aristotle, Avicenna, Robert Boyle, Henning Brandt, Antoine Lavoisier, John Dalton, Joseph Proust, Alfred Nobel, Mendeleyev, Marie Curie and Niels Bohr.

The game has been structured in five main levels corresponding to a different moment in history: the Prehistory, Ancient Age, Middle Ages, Industrial Revolution and Contemporary Age. Each level is divided in several stages.

In Al-Kimia, all the objects, challenges and actions are linked to the scientific knowledge available at each moment in history. In order to advance in the game, players must acquire basic chemical knowledge and perform experiments that were crucial in the development of Chemistry as a scientific subject.

11.6.2 Applying the Theoretical Framework in the Real World

The starting point of the game design process was the factual information provided by members of the Faculty of Chemistry of the University of Santiago de Compostela. The most important chemical discoveries across the ages were selected and situated within their historical context. Based on this content, the members of the video game team of the Faculty of Social Sciences and Communication of the University of Vigo designed the different elements of the game, as defined in the chosen theoretical framework.

Figure 11.6 illustrates how the different elements of the chosen game design framework were adapted to the specific requirements of the Al-Kimia project.

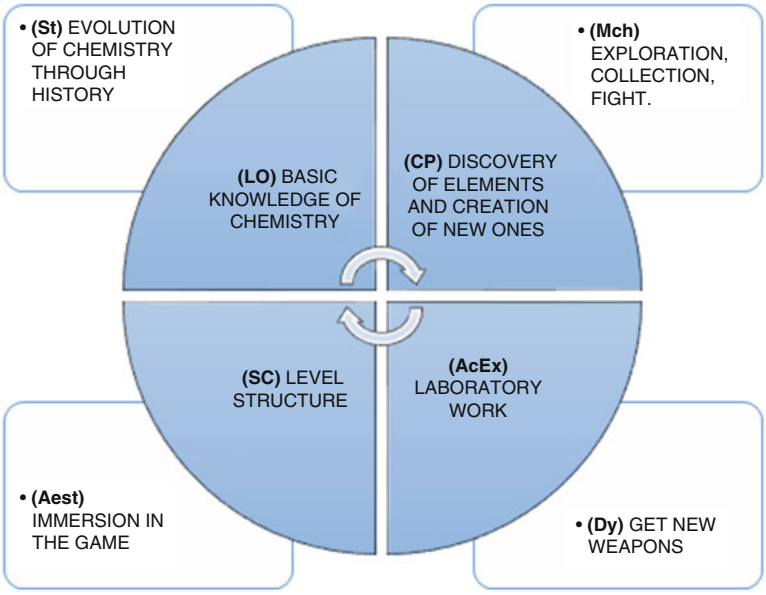

Fig. 11.6 Adaptation of the framework for the design of an educational video game to Al-Kimia

Fig. 11.7 Screenshot of Al-Kimia: Prehistory level

To further illustrate how the framework has been used in the game design process, a detailed description of the first level of the game is provided as an example. This level corresponds to prehistoric times (see Fig. 11.7).

Learning Objectives (LO) To discover the first chemical elements discovered in nature and how their combination enabled the human race to evolve

The Story (St) Will be based on the concepts to be explained and will provide information on how to achieve the objectives.

Challenge (Problems) (CP) How to find the chemical elements, combine them to create new ones and defeat the enemies. Players must create weapons with wood and fire, create protective clothing with the pelts of animals they have defeated, bake clay pots and, finally, discover the use of metals.

Mechanics (Mch) To progress in the game, players must undertake exploration, collection and fighting tests. As each level is solved, a new page appears in the book.

Active Experimentation (AE) Players will have to use their knowledge of the game and their skills to progress in the game.

Dynamics (Dy) The following tests need to be solved:

- A tree is burning. A stick needs to be collected and set alight. Fire has been discovered.
- Some clay needs to be collected. Players will be able to mould it into bowls using water from a nearby stream.
- Clay needs to be baked to harden the bowls which can also be used as weapons.

- Metal can be discovered in the river.
- Animals need to be defended against using new weapons.
- Animal pelts can be used as protective clothing.

Schemata Construction (SC) By actively experimenting, players will learn the basics of playing the game: how to use their avatar, how the game is structured, the way its economy works and what challenges need to be overcome. Most importantly, they have also started to learn about Chemistry and how it has helped the progress of the human race.

Aesthetics (AE) Players will use an avatar in a third-person, isometric view. Each level will consist of a single space that can be explored interactively. As players solve challenges, new things happen in the virtual space. This first level is set in nature to be consistent with the historical setting. It will consist of several fields, a river and a cave (where the use of colour and cave paintings will be introduced).

The objective is that, by combining all of the above elements, players will reach a state of *flow*.

11.7 Results

In order to evaluate the effectiveness of Al-Kimia in achieving its objectives, both pre- and postlaunch research studies were designed. A QUAN + qual design was chosen (Creswell 2009). The quantitative approach was given a higher priority in the study, whilst qualitative research was undertaken during the same data collection period.

In the prelaunch study, high school students from several schools in both rural and urban areas were required to complete an online questionnaire with closed-ended questions. Accidental sampling was used as the method to choose the sample of the study. Further information on the sample that was used in this study can be found in Table 11.1.

There are two objectives to these studies:

- Objective 1: to baseline current knowledge on Chemistry and how it relates to everyday life amongst the target population
- Objective 2: to measure the impact that playing Al-Kimia may have in changing this knowledge

Table 11.1 Sample of the prelaunch study: schools and students

Schools	Students (by Spanish school year)
Seven schools in urban areas (four in Santiago de Compostela and three in Vigo)	14–15 years old (third year ESO), 299
	15–16 years old (fourth year ESO), 413
Five schools in rural areas	16–17 years old (first bachillerato), 203
	17–18 years old (second bachillerato), 162

The prelaunch survey included references to the following four dimensions:

- The relationship between Chemistry and people's health and emotions
- The relationship between Chemistry and everyday life (painting, building, medicine)
- The role of Chemistry in subjects like education and caring for the environment
- The effect of digital tools on the learning process

The data obtained in the prelaunch survey was captured and analysed using Microsoft Excel. The analysis of variance (ANOVA) was done using SPSS. No statistically significant variations were detected between the different schools that took part in the study, so the results were analysed globally.

Without going into too much detail, the results of this prelaunch study show that Chemistry is still a relatively unknown subject; it is perceived as important in health-related issues, but there isn't a clear understanding of how it affects everyday life. Finally, there is a positive perception amongst respondents about using digital tools as learning tools.

At the time of writing, shortly after the release of the game, the postlaunch study hasn't taken place yet. Apart from focusing on the dimensions of the prelaunch survey, it will include an additional dimension: the structure of the video game itself.

The expected responses will help determine whether this title has achieved its objective of changing attitudes towards Chemistry amongst Spanish high school students.

11.8 Conclusions

As has been mentioned above, designing video games is not an art; it is a craft. In the case of Al-Kimia, it has become evident that this craft becomes even more complicated if players are required to learn as well as being entertained. The challenge is double: to create a solid interactive entertainment title whilst providing a valid and rich learning experience. A balance between these two factors, entertainment and learning, must be achieved if the end result is to be successful. The use of the new, hybrid game design framework presented above ensures that these two factors are aligned.

It is still too early to know if the objectives of the game have been met, as the postlaunch research has not been completed at the time of writing. One result is clear, however: the process of designing this video game has enabled both Chemistry professors and video game designers to gain an understanding and appreciation of their counterparts' area of expertise. This has proven to be an enriching experience for everyone involved in the project and could give rise to further collaboration in the future.

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