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# SERIOUS GAMES TO COPE WITH THE GENETIC TEST REVOLUTION

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# Abstract

TECHNOLOGICAL progress and the lowering of DNA sequencing costs have made genetic testing increasingly accessible to the general public. However, this progress does not reflect an increased genetics literacy in lay people that at present remains poor. Thus almost everyone has the possibility to undergo genetic testing independently, but the diffuse lack of knowledge may lead to misinterpretation of genetic information and result in negative consequences for personal health decisions. Several policies have been developed to try to address this issue. The most appropriate one is to educate people about genetic concepts and genetic test interpretation, to empower them in order to make responsible health-related decisions. To reach this goal the Serious Games (SG) approach seems very promising as it has been shown to be very powerful in education, training, health promotion, and socialization. This is why SG appear an attractive means to communicate genetic concepts to the general public. The aim of this research is to study the feasibility of using SG as a highly interactive medium to encourage experiential learning, increase literacy and promote self-efficacy in the genetic-related decision-making process. For this purpose, we explore state-of-the-art of Serious Games related to genetics, discussing whether these games are an adequate instrument to increase literacy and self-efficacy in the general public. Based on this analysis we design, develop and test a suite of SG specifically tailored to educate people about genetic concepts and genetic testing. To maximize the efficacy and mass

appeal, the level of complexity of genetic information was balanced with the intent of making comprehensible and usable games. We believe that our approach –development and validation, using an evidence-based approach, of customized arcade games to convey basic genetics concepts together with the use of the "Adventure Game" genre to relate the individual genetic risk with lifestyle factors– is completely new in this field. We conclude by discussing results about usability/playability, knowledge transfer and self-efficacy promotion in the field of health-related decision making, analysing data collected during monitored playing sessions.

*Some images, tables and contents of this thesis have been previously published in [1]- [2].*

# Riassunto

Il progresso tecnologico e l'abbassamento del costo di sequenziamento del DNA, hanno reso i test genetici sempre più accessibili al pubblico. Questo sviluppo però non procede di pari passo con la scarsa conoscenza che la gente comune risulta avere in ambito genetico. Oggi giorno è possibile sottoporsi ad un test genetico autonomamente senza il consulto medico, ma la diffusa carenza di consapevolezza e informazione in questo ambito può portare ad un fraintendimento dei risultati genetici ottenuti e quindi a possibili conseguenze negative per quanto concerne le decisioni relative alla propria salute. Per cercare di porre rimedio a questa lacuna sono state sviluppate diverse policy. Tra queste, la necessità di educare la gente sui concetti di genetica assume un rilievo di particolare importanza. Si vuole infatti cercare di potenziare la consapevolezza della cittadinanza, favorendo prese di decisione in ambito medico più responsabili. Per ottenere questo risultato l'impiego di Serious Games (SG) sembra uno tra gli approcci più promettenti. I SG hanno infatti mostrato ottimi risultati se impiegati in ambiti quali l'educazione, l'addestramento, la promozione della salute e la socializzazione; ecco dunque perchè sembrano essere un valido strumento per divulgare concetti di genetica tra la gente comune. Lo scopo di questa ricerca è studiare la possibilità di utilizzare i SG come media fortemente interattivo per incoraggiare un apprendimento esperienziale, aumentare la conoscenza e promuovere il processo cognitivo dell'autoefficacia nel contesto dei processi decisionali in ambito genetico. Per ottenere questo

risultato esploriamo lo stato dell'arte dei SG legati alla genetica e discutiamo sulla possibilità di farli utilizzare dalla gente comune. Successivamente progettiamo, sviluppiamo e testiamo una suite di SG su misura per educare la gente sui concetti di genetica e di test genetico. Lo sviluppo e la validazione di videogiochi arcade custom per illustrare concetti di genetica di base e l'utilizzo del genere "Adventure Game" per mettere in relazione il rischio genetico individuale ai fattori dello stile di vita, risulta essere, sulla base delle nostre ricerche, completamete nuovo in questo ambito. Concludiamo infine presentando i risultati della ricerca condotta testando i videogiochi sviluppati per quanto riguarda la loro usabilità, la capacità di trasferire conoscenza e migliorare il processo cognitivo nell'ambito dei processi decisionali in ambito medico e analizzando i dati collezionati durante le sessioni di gioco.

*Alcune immagini, tabelle e contenuti di questa tesi sono state precedentemente pubblicate in [1]- [2].*

# Contents


**1 Introduction** **3**

1.1 Genetics today - What to expect? . . . . . 3
1.2 Prêt-à-porter Genetic tests . . . . . 5
1.3 What's the problem? . . . . . 7
1.4 The Mind the Risk Project . . . . . 8
1.5 Thesis Contribution . . . . . 10
1.6 Thesis Organization . . . . . 12

**2 Can technology help people cope with this genetic revolution?** **15**

2.1 From voice to paper to bits. How technology has changed knowledge transfer . . . . . 16
2.2 Genetics concepts . . . . . 17
2.3 Interactive multimedia to learn Genetics . . . . . 17
2.4 Serious Games as the new paradigm to increase genetics literacy and self-efficacy . . . . . 21
2.5 Genetics Serious Games – State of the Art Analysis . . . . 21
2.5.1 *DNA Roulette* . . . . . 22
2.5.2 *Niche* . . . . . 24
2.5.3 British TV station - Channel 4: *Ginger Dawn, Sneeze, DNA Heroes, Breeder* . . . . . 25
2.5.4 *Touching Triton* . . . . . 29
2.5.5 *Geniverse* . . . . . 31
2.5.6 *DNA-The double helix* . . . . . 31

2.5.7 *PaJama* . . . . . 32
2.5.8 *Angel Breed* . . . . . 32
2.5.9 MD-Bio . . . . . 34
2.5.10 *Thingdom* . . . . . 35
2.5.11 *Dragon Breeder* . . . . . 37
2.5.12 *Transcription Heroes* . . . . . 37
2.6 Are these games feasible for the general public? . . . . . 39
2.7 Games for Learning: an evidence-based approach . . . . . 41

**3 Serious aspects** **43**
3.1 Serious Games Definitions: . . . . . 43
3.2 Why are Serious Games so powerful? . . . . . 44
3.2.1 Learning through Serious Games . . . . . 45
3.3 Relevant Psychological theories about Learning . . . . . 46
3.3.1 How people learn? The Cognitive theory of learning 46
3.3.2 The Self-Efficacy Theory . . . . . 48
3.4 Games for Learning . . . . . 50
3.5 The right mix of serious and game . . . . . 50

**4 Gaming aspects** **53**
4.1 Motivation: Internal and External . . . . . 54
4.2 What makes games fun? . . . . . 55
4.3 Self-Determination Theory . . . . . 58
4.4 Best Practices for a Good Game Design . . . . . 59
4.4.1 Meaningful Play . . . . . 59
4.4.2 Clear immediate feedback . . . . . 60
4.4.3 Simple and direct interaction . . . . . 60
4.4.4 Challenge . . . . . 61
4.4.5 Fantasy . . . . . 61
4.4.6 Curiosity . . . . . 62

**5 Design and Development of Games for Learning related to Genetics** **63**
5.1 Design Techniques User-Oriented . . . . . 63
5.1.1 Design Thinking Process . . . . . 64
5.1.2 Human Centred Design . . . . . 65
5.2 Interdisciplinary team for content decision . . . . . 67
5.2.1 Games Content and Genetic topics review . . . . . 67

5.3 Genetics contents chosen for the Mini-Games . . . . . 68
5.3.1 Heredity . . . . . 69
5.3.2 Mutation . . . . . 71
5.4 Initial prototypes of the games . . . . . 72
5.4.1 Simulation of heredity . . . . . 72
5.4.2 Simulation of Susceptibility: . . . . . 73
5.4.3 From simulation to game: Susceptibility V 2.0: Sushi-eptibility . . . . . 76
5.4.4 Susceptibility V.3: Ambient, ageing and mutation: . 76
5.4.5 Simulation of a healthy lifestyle . . . . . 77
5.4.6 Gene Interaction - first prototype . . . . . 79
5.4.7 PACMAN Gene Interaction - second prototype . . . 81
5.5 Choose the right genre for a wide audience . . . . . 81
5.5.1 Runner Game . . . . . 83
5.5.2 Arcade . . . . . 83
5.5.3 Adventure Game . . . . . 84
5.6 Software used . . . . . 84
5.7 Platform and Use case . . . . . 84
5.8 Questionnaire System developed to test knowledge transfer 85
5.9 System for logging players' choices . . . . . 86

**6 Games developed and tested: description of the final version 87**
6.1 Heredi-Rabbit . . . . . 88
6.2 MutanTetris . . . . . 90
6.3 Gene Adventure . . . . . 93
6.4 Knowledge Transfer and Self Efficacy promotion through our Serious Games . . . . . 99
6.5 A possible approach to the integration of the mini-games into the Adventure Game . . . . . 101

**7 Defining the experimentation protocol to test the games 105**
7.1 What to test . . . . . 105
7.2 Test for playability . . . . . 106
7.2.1 Experiment Description . . . . . 107
7.3 Test for knowledge transfer and self-efficacy . . . . . 107
7.3.1 Target population and recruitment . . . . . 108

7.3.2 Experiment description . . . . . 108

**8 Playability test results** **111**
8.1 Results . . . . . 113

**9 Testing Knowledge Transfer and Self Efficacy** **119**
9.1 Preliminary results about Knowledge Transfer . . . . . 120
9.1.1 Statistical Analysis . . . . . 123
9.2 Preliminary results about Self Efficacy . . . . . 126
9.2.1 Statistical Analysis . . . . . 128

**10 Conclusion** **133**
10.1 About Playability test results . . . . . 135
10.2 About Knowledge Transfer and Self Efficacy results . . . 135
10.3 General comments . . . . . 136
10.4 What's next - Limits and future proposal . . . . . 136

**Appendix A Genetic Glossary** **139**
A.1 Abbreviations: . . . . . 141

**Appendix B Knowledge transfer Questionnaire pre and post** **143**

**Appendix C Self-Efficacy Questionnaire pre and post** **153**

**Appendix D Game Experience Questionnaire subset for media comparison** **159**

**Bibliography** **161**

# List of Figures

1.1 Wetterstrand KA. DNA Sequencing Costs: Data from the NHGRI Genome Sequencing Program (GSP) Available at www.genome.gov/sequencingcostsdata. . . . . 5

2.1 Several approaches could be used to transfer information and knowledge. The advent of technology has opened a new way of knowledge transfer. Interactivity is a game changer feature for content fruition. It could enhance engagement and gives users the possibility to set their own peace in content exploration. . . . . 17

2.2 The Genetic Science Learning Center, University of Utah, has created one of the most comprehensive English-language websites to learn genetics. Image found on the Web. Retrieved from [3] . . . . . 18

2.3 The user must click on a chromosome in the pool on the left and drag it next to its partner in the karyotype on the right. There is also the possibility to turn on hints to have an outline of the matching chromosome. Image found on the Web. Retrieved from [3] . . . . . 19

2.4 In this puzzle game the player, in order to become a good pigeon breeder, needs to know how to pair birds to get offspring with just the right combination of characteristics required. Image found on the Web. Retrieved from [3] . . 20

2.5 DNA Roulette: The player is introduced to an imaginary person and asked to bet if this person will or will not develop a trait or disease. Image found on the Web. Retrieved from [4] . . . . . 23
2.6 The goal of the game Niche, consists of shaping an animal tribe and finding an ecological niche for it to live in. Image found on the Web. Retrieved from [5] . . . . . 24
2.7 The goal of the game is to help our red hair hero to spread his recessive ginger gene, reproducing with as many women as possible. Screen-shot taken from the game. . . . . 26
2.8 In this fast-paced game player must infect as many people as possible with a chain reaction sneeze in different environments and settings. Screen-shot taken from the game. . 27
2.9 Through the rapid press of four keys in the correct rhythm and sequence the player should join the combinations of DNA strands to win. Screen-shot taken from the game. . . 28
2.10 In this simulation, the player can create a unique organism and then look for the organism of other players combining them to get a new breed with the desired characteristics. Screen-shot taken from the game. . . . . 29
2.11 The player should keep the six crew members in a 20-year mission alive, analysing medical records, genetic and family history data to determine a crew member's risk for six common complex diseases. Image found on the Web. Retrieved from [6] . . . . . 30
2.12 The game encourages users to breed and study a population of virtual dragons in order to understand the fundamental mechanisms of heredity and genetic diseases. Image found on the Web. Retrieved from [7] . . . . . 31
2.13 The player has to complete the exact copy of a double-stranded DNA and has to associate it with the right organism. Image found on the Web. Retrieved from [8] . . . . . 32
2.14 Pajama game is a simulation of fishes breeding based on the fundamental laws of heredity. Image found on the Web. Retrieved from [9] . . . . . 33

2.15 The player should try to produce fish with rare characteristics and then resell them and earn money to buy even more valuable fish. Screen-shot taken from the game. . . . 34
2.16 The player must correctly classify the genotype contained in the bubbles by dragging them into the correct hole to get bonus points. . . . . 36
2.17 The player must specify the type of mutation expressed in the DNA of wild-type fish (e.g. added, deleted or substituted). Screen-shot taken from the game. . . . . 36
2.18 In this game, the player can interact through the mouse with the "Things" like in a sort of Tamagotchi and make it grow and reproduce with other "Thing" to achieve the characteristics required to win the game through the next generations. Image found on the Web. Retrieved from [10] 37
2.19 The player applying the concepts of Mendelian genetics must be able to generate new dragons with well-defined genetic characteristics. Image found on the Web. Retrieved from [11] . . . . . 38
2.20 In Transcription Heroes, the user presses four keys, representing the nitrogenous bases, and must reconstruct the DNA. Image found on the Web. Retrieved from [12] . . . 39

3.1 A cognitive theory of multimedia learning: people process auditory/verbal vs. visual/pictorial information through different channels. The limited ability to process this multichannel information is the bottleneck of the whole process. Learning happens if people have adequate cognitive processes. Representation of "The Cognitive Theory of Multimedia Learning" by Richard E. Mayer . . . . . 48

5.1 The Design Thinking process is an iterative and flexible process able to bring ideas to life based on how real users think and behave. . . . . 65
5.2 The Design Thinking process is an iterative and flexible process able to bring ideas to life based on how real users think and behave. . . . . 66

5.3 This is the first prototype developed to focus on heredity. The player is presented with a 3D mini-world on which two different populations, identified by two colours, live. The blue population, which represents the dominant characteristic and red, which represents the recessive characteristic. It is possible to tune some population parameters to create a multitude of scenarios thereby illustrating all the different aspects of Mendelian inheritance. . . . . 74

5.4 The first prototype of a micro-world, developed to illustrate the probabilistic nature of the genetic susceptibility to a disease. The player has the ability to simulate the passing of time to verify how the disease will manifest itself on part of the population. Subjects who manifest the disease change their colour from green, healthy people, to orange, sick people and then end up with the red colour that represents the onset of death. . . . . 75

5.5 The player must select ten pieces of sushi that may or may not be rotten. The player is then asked to choose which of the 10 pieces caught to eat. If the player draws a piece of good sushi he can continue to the next level, otherwise, the game ends, underlining the probabilistic concept of the onset of disease. . . . . 77

5.6 The player needs to feed herself to survive and be able to continue in the game. To do this she must choose whether to enter or not in the various sushi restaurant present on her path. Inside the restaurant, the player will have to randomly fish a single piece of sushi. Some pieces of sushi while appearing edible are poisoned and cause a game over when eaten. Sushi bars near polluted environments have a higher number of contaminated sushi pieces. . . . . 78

5.7 The player, in the role of a god, must make the people who live in the world created by her survive as long as possible. To do this she can decide what kind of food to use to feed the population. . . . . 79

5.8 We decided to implement the use of metaphors within a puzzle game to explain the concept of gene interactions. Each gene in the game is represented by a bridge. In each level, the player must be able to bring several cars safely to a destination by activating the right sequence of bridges. This activation, however, will change the state of the other bridges, thus recalling the concept of interaction between different genes. The player, through the game, learns to understand the rules of interaction of different genes and must try to minimize the number of moves necessary to bring all the cars to the arrival. . . . . 80

5.9 In our revised version of the Pacman, the only difference from the original is how the fruit bonuses are generated and how they influence Pacman's behaviour. When two or more genes collide they give rise to a particular fruit that falls in the game area and can be consumed by the player. The fruit generated from time to time will give special powers to the Pacman, sometimes positive while other times negative. By implementing these dynamics, we explain to the player how the interaction of some genes can modify the phenotype of a living being. . . . . 82

6.1 a - The player is introduced to the game with an overview of genetic concepts (gene, alleles, genotype, phenotype); b - It is possible to test how Mendel's law works. . . . . 89

6.2 Screenshot of the initial prototype version of the game. . . 90

6.3 a - The player controls the rabbit that should grab carrots to get energy and avoid traps; b- The player can choose to have the running rabbit mate with other incoming rabbits based just on their phenotypes and have an offspring; c- The newborn rabbit inherits the genetic make-up following the Mendel's laws. If the target genetic make-up is achieved (goal) the game ends. . . . . 91

6.4 The virtual narrator gives to the player an introduction about the fundamentals aspects of cell duplication(a) and duplication errors using simple animated illustrations. An interactive part is also presented to the player (b), that must duplicate a predefined amount of cells avoiding duplicating cells containing errors. . . . . 92
6.5 The Mutant-Tetris. The classical Tetris is enriched with several new mutated blocks. The blocks represent the genetic material and the elimination of a row represents the correct encoding of the DNA. In figure a and figure b, the two fixable mutated bricks increase the difficulty in deleting lines. In figure c the mutated brick has a geometry that does not allow in any way the deletion of rows. . . . . 93
6.6 Eugene is going to buy a Direct To Consumer Genetic Test online(a). After a while he receives the results of the test, discovering his high risk for cardiovascular disease. . . . . 94
6.7 The player chooses if Eugene must talk to his doctor about cardiovascular disease and genetic risk. . . . . 95
6.8 The “smile icons” colours and expressions represent Eugene’s health status. . . . . 96
6.9 During the adventure the player should carefully choose what to eat, this to maintain correct nutrition habits. . . . . 97
6.10 During Gene Adventure Eugene should carefully choose how to manage physical activity to maintain a good lifestyle. . . . . 97
6.11 The report given to the player at the end of the game. The button required to proceed is positioned at the bottom of the report, to encourage the player to read and not to skip the text. . . . . 98
6.12 The proposed solution to integrate under one roof all the mini-game experiences and the adventure game. This is in order to make these two different contents as integrated as possible. The Players, while playing the adventure game, can decide to go to the game room and play all the mini-games developed to teach basic genetic concepts. . . . . 103

9.1 Mean and Standard Deviation of the PRE and POST Test. . 122
9.2 Mean and Standard Deviation of the PRE and POST about the Self Efficacy Test. . . . . 127

# List of Tables

8.1 Socio-demographic characteristics of game players and frequencies of devices and video games use. . . . . 112
8.2 HeredyRabbit usability issues. . . . . 114
8.3 MutanTetris usability issues. . . . . 115
8.4 GeneAdventure usability issues. . . . . 115
8.5 Mean and Standard Deviation(SD) scores for Competence, Immersion, Flow, Tension, Challenge, Negative Affect and Positive Effect in HeredyRabbit, MutanTetris and Gene Adventure-Wt players. . . . . 116

9.1 The number of correct answers of the knowledge transfer questionnaire, filled in before and after the game session. . 121
9.2 The scores of the self-efficacy pre-test. . . . . 130
9.3 The scores of the self-efficacy post-test. . . . . 131
9.4 Score difference of the Self-Efficacy test Pre & Post . . . . 132

D.1 The subset of used question taken from the Game Experience Questionnaire. . . . . 160
D.2 Il sottoinsieme di domande prese dal Game Experience Questionnaire. . . . . 160

CHAPTER 1

# Introduction

> Every man is born an original, but sadly, most men die copies.
>
> Abraham Lincoln

## 1.1 Genetics today - What to expect?

The human genome is made up of 23 chromosome pairs with a total of about 3 billion DNA base pairs. No two humans are genetically identical, typically the difference between the genomes of two individuals is estimated at 20 million base pairs (which represents 0.6% of the total genome). But how did we discover this?

The genetic revolution starts as far back as 1865, when Gregor Mendel, the father of modern genetics, presented his research on experiments in plant hybridization to the scientific community. Since then a sequence of important discovery occurred, in 1953 James Watson and Francis Crick discovered the double helix structure of DNA, the first genetic disease (Huntington's Disease) was mapped in 1983 and in 1990 the Human Genome Project started, giving an incredible boost in this field. The goals of the Human Genome Project are to analyse the 3 billion DNA

base pairs of the human genome and to find the estimated 20,000 human genes. The Project also aims to sequence the genome of several other organisms that are important to medical research. Another relevant aspect of the Human Genome Project is the will to develop new tools to obtain, analyse and make genetic information widely available. Because these new findings have consequences for individuals and society, the Human Genome Project is exploring the consequences of genomic research through its Ethical, Legal, and Social Implications (ELSI) program.

Due to these advances, genetics is more and more present in our everyday lives. Progress in technology and bioinformatics leads to a lowering of DNA sequencing costs and to a better comprehension of the DNA code. We are now migrating from an epoch of DNA reading/sequencing only technology to the epoch of writing technology [13]. These incredibly fast and disruptive discoveries affect our lives and the lives of our future generations. All these advances are bringing incredible innovations in several fields and the most affected and relevant is medicine. Scientists are now exploring new Gene therapy, a totally new approach to treat cancer, genetic diseases, and infectious diseases. But this ability to edit DNA creates huge ethical problems. It's today possible to reprogram a cell of the skin and bring it back to a stem cell (Induced Pluripotent Stem Cell - iPSC) and then control its growth, by transforming it in a liver cell, into a neuron cell and even into an egg cell. Even more, with the CRISPR-CAS9 technique, we are now able to edit specific parts of the DNA. Progress in this field is bringing an incredible innovation in medicine, but such an incredible discovery has lights and shadows as it can be used for extremely good purpose but also with evil scope in mind.

Given these incredible recent discoveries, what should we expect from the future? In which direction are we moving? Are we moving too fast? Is the general public ready for this revolution? Are we going to interfere with future generations? Will it be ethical to use this technology as therapy? And can we employ it for people's empowerment? In this society that runs very fast, we should discuss this revolution with the public, and give them instruments to understand where we are going. Only emancipation and knowledge could bring science to new frontiers in a safe and noble way.

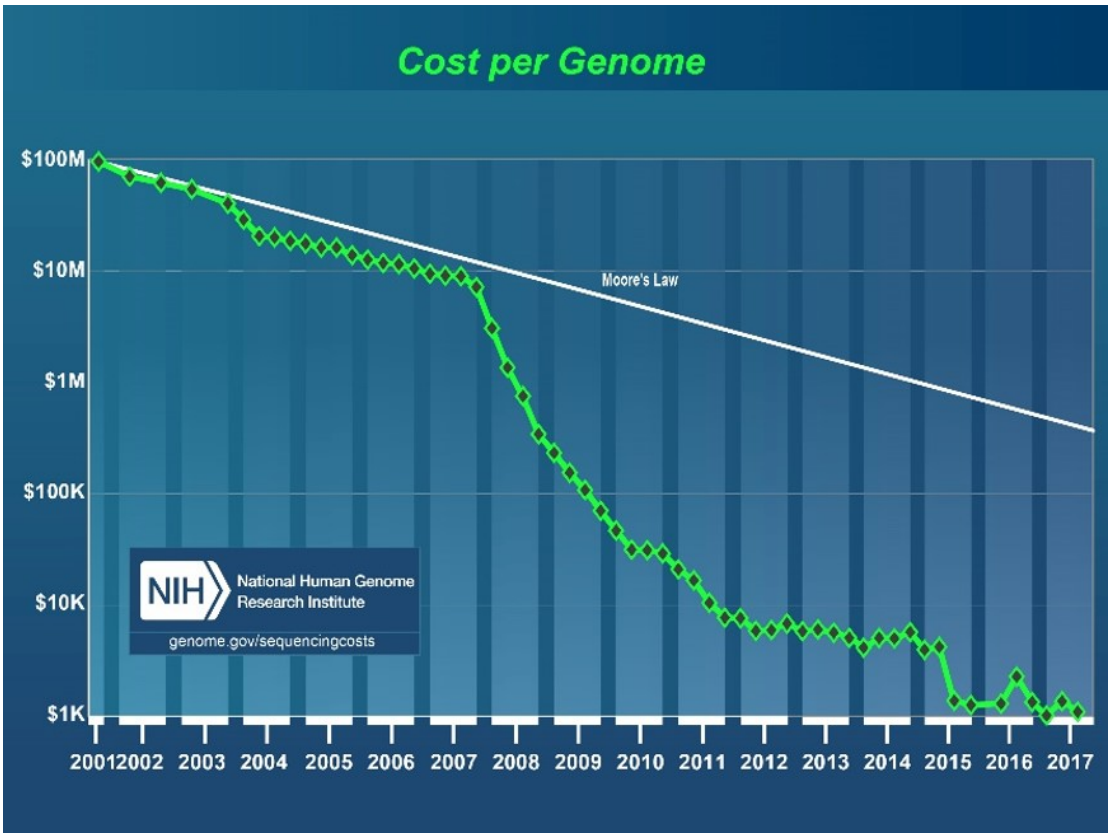


**Figure 1.1:** *Wetterstrand KA. DNA Sequencing Costs: Data from the NHGRI Genome Sequencing Program (GSP) Available at www.genome.gov/sequencingcostsdata.*

In the work done in this thesis, we could not provide an answer to all these important and urgent questions. Our aim is to introduce the reader to the complexity and heterogeneity of the topic we are dealing with, focusing in detail on a subproblem arising today from a specific use of genetic technology: the possibility given to the general public to easily undergo genetic testing.

## 1.2 Prêt-à-porter Genetic tests

In the previous paragraph, we have introduced some of the newest discoveries in the field of genetics. Most of them are just proofs of concepts and years of development and testing are required to make them ready for human use. Some of the incredible discoveries obtained during the Genome Project are, however, now ready for the general public.

Figure 1.1 illustrates the speed of progress related to the DNA sequencing costs. In the last few years the cost per genome is considerably

decreased. With current technology, we can sequence an entire human genome for about 1,000$ in a few days. A very short amount of time is required to read all the information contained in our DNA but what does this information really represent? We know very little about it. The large part of the Genome's functionalities are still unknown, even so, scientists in the last couple of decades were able to identify some important genes that contribute significantly to human health. This discovery provides the possibility to execute a genetic test on human biological samples and identify possible predisposition to diseases.

Genetic tests (GT) are clinical tests that identify changes in chromosomes, genes, or proteins that may be related to an increased chance of an individual to inherit or develop a disorder or a disease [14]. In the last years, genetic tests have gained importance for personalized medicine and disease prevention; they are usually prescribed by physicians to healthy individuals who have a family risk of developing a certain illness or to patients who are supposed to have a genetic mutation responsible for their actual disease [15].

This opened the door to the availability on the market of many Direct-To-Consumer Genetic Tests (DTC-GT) made accessible to the general public, without the need of an intermediary medical professional. This means that almost everyone has the possibility to undergo genetic testing independently, with implications for personal and public health.

Since 2002 [16] people have been able to autonomously decide to buy genetic tests to obtain more information about their genetic predisposition to disease development through the internet or from local private companies that sell DTC-GT. The increasing success of such services brings us to hypothesize that people desire to acquire this health information by themselves even if not strictly required by their physicians or by a familial predisposition to certain illnesses [17]. Indeed, proponents of DTC-GT services argue that making consumers able to calculate their relative risk of developing certain diseases may result in increased patient awareness, improved compliance with health-screening practices, and with a greater ability to make healthy lifestyle choices [18]- [19].

## 1.3 What's the problem?

All this progress and advancement could bring incredible benefit to the health of the people, but at what cost? Do advancements in genetics have only pros and no cons? Just by having a look at the cinematography about genetics we can find that in 1997 the movie "GATTACA" [20] illustrates that in "the not-too-distant future", liberal eugenics is common. A genetic registry database uses biometrics to classify people created through DNA editing as "valid", while those conceived by traditional means (more susceptible to genetic disorders) are classified as "in-valid". Furthermore, although genetic discrimination is illegal, in practice, genotype profiling is used to identify "valid" individuals to qualify for professional employment, while "in-valids" are relegated to lower level jobs.

This is an extreme vision of the future, but how much will genetics impact everyday life? What do lay people know about genetics? Are they informed and aware about results that they could obtain? And when they obtain DTC-GT results, do they have enough information and competence to make an accurate health-related decision?

The current issue is that genetic testing and genetic risk information have become the new frontier of personalized medicine and disease prevention [21]. Moreover, with the introduction of DTC-GT, people autonomously evaluate the credibility and utility of genetic information, which has implications for both personal and public health, without having enough competencies in this field [22].

Based on research conducted by Chapman et al. [23], the scenario is quite alarming. This new incredible possibility to obtain health-related information does not go hand-in-hand with the lay people's knowledge in the field of genetics. In fact, genetic literacy among the general public is still very poor [24]- [25].

Despite these expectations, available data about the effects of DTC-GT on consumers are not encouraging at all. People usually have great difficulties in understanding genetic risk information and their implications for health. Upon receiving genetic results, they sometimes experience unnecessary anxiety or emotional distress, resulting in making decisions about their health based on incomplete information that often results in increased healthcare costs [17]- [18]- [19]. Moreover, expected

changes in the consumers' lifestyle habits are rare and usually restricted to the few weeks following the test results [26]- [27]- [28]- [29].

These data suggest that the increasing diffusion of genetic testing does not reflect an increased knowledge and awareness concerning genetic risk significance in the general public.

This diffuse lack of knowledge may lead to misinterpretation of genetic information and may have possible negative consequences for personal health decision [22].

"The range of DTC-GT available is progressively increasing, but legislation and government oversight at the international level are insufficient to provide and to monitor regulatory control over these activities. Only through the international cooperation among genetic literacy and policy-makers, among the media and the general public, will it be possible to overcome the challenges introduced by DTC genetic testing services" [30].

For this reason, several policies have been developed to fill this gap [31]. One of the most promising is to educate people about genetic concepts and the meaning of genetic test results thereby empowering them to make responsible health-related decisions [32].

We believe that the increasing impact of genetic testing and genetic decision making in health and disease prevention makes it important to educate the public on these matters. Without such knowledge, individuals are more likely to make uninformed decisions or to handover all decisions about genetic testing to their doctors.

## 1.4 The Mind the Risk Project

This work fits into the broader project "Mind the Risk" (MTR), "an international six-year multi-disciplinary research project to provide a framework that may guide regulation and management of genetic and related risk information in various settings" [33].

There are pressing ethical concerns and a need to improve clinical practice. The aim of the project is to provide a philosophical and conceptual framework that together with historical and socio-cultural analyses of concerns about risk information, empirical investigations of risk, ethical analyses, perceptions and preferences may guide regulation and

management of genetic and related risk information in various settings.

The project is working to:

- Develop a conceptual framework for genetic risk information and management.
- Assess perceptions and evaluations of genetic risks in different stakeholder groups.
- Assess the ethical, psychological and social implications of the provision of risk information from genetic and related technologies.
- Explore new forms of communication and information developing tools to improve communication skills regarding genetic risk information.

The contribution of this thesis to the MTR project is focused on the use of new technologies to improve literacy in lay people. The goal is to try to respond to some basic knowledge needs necessary to make informed medical decisions and illustrate the implications that these new direct to consumer genetic tests can have in our lives.

## 1.5 Thesis Contribution

Addressing our research questions, this thesis adds the following contributions to the current state-of-the-art:

1. We conduct a systematic review of the games related to genetics and identify current trends and limits.

2. We propose what we believe are the pillars of genetics required by the general public to better understand genetic risk and genetic test results.

3. We propose a set of possible approaches to address knowledge transfer through SG using metaphors to highlight and present genetic concepts, customizing famous arcade games and using a dramatic curve narrative to balance the serious content and the entertainment part.

4. We designed, developed and tested for playability three SG related to genetics. Two are specifically designed for knowledge transfer about basic genetics concepts (heredity, mutation) and one for both knowledge transfer and self-efficacy promotion in order to put together the individual genetic risk, as derived by DTC-GT, with lifestyle factors (physical activity, diet, and social interaction) in order to better understand the role of genetics and environmental factors in the person's risk to develop a disease or to inherit a trait or condition.

5. We developed a log system to keep track of all the choices made by the player during the game, in order to further evaluate their decision-making process and possible variations in changing behaviours.

6. We evaluated the developed SG effectiveness in terms of learning outcomes in the field of genetics and genetic risk. In particular, we:

    - assessed the learning impact of a suite of mini-games on participant's knowledge and understanding of basic genetic concepts;

- assessed the effect of an adventure game on the participant's skills and perceived self-efficacy concerning genetic risk management.

## 1.6 Thesis Organization

This thesis is organized as follows:

In **Chapter 2**, we introduce how the evolution of technology has changed the way we communicate and transfer information, completely revolutionizing the concept of storytelling. We present how interactive multimedia material is used to teach Genetics and we propose the use of Serious Games as the new paradigm to increase genetics literacy and self-efficacy in lay people. We then analyse the state-of-the-art of SG related to Genetics. We identify current trends and discuss their possibility to be used by lay people.

In **Chapter 3**, we explore the definitions of serious games by analysing some of the most famous ones provided by experts in the field. We then introduce the psychological theories involved in both the learning process and in games for learning, which have as their main objective the improvement of the knowledge and cognitive abilities of the players.

In **Chapter 4**, we introduce the theories used to make games fun. We analyse good game design principles highlighting why is so important for SG to balance the serious part with the entertaining part. We then detail the solutions we took to support effective and accessible SG for lay people.

In **Chapter 5** and **6**, we describe our design and development process, we present our idea of choosing the most appropriate game genre for our target audience. We describe the deployment platform and the possible use case scenarios of the developed SG, and we finally describe them in-depth.

In **Chapter 7**, we delineate the implemented research protocol used to test the games to assess usability/playability, knowledge transfers and self-efficacy promotion.

In **Chapter 8** and **9**, we discuss the results of our work, detailing

the usability/playability of the games, the subjective experience of the players and the validation tests performed on our SG to evaluate their effectiveness.

In **Chapter 10**, we conclude with a discussion on our results on benefits and drawbacks presenting both ongoing and future work regarding SG related to genetics.

CHAPTER 2

# Can technology help people cope with this genetic revolution?

> Technology alone is not enough.
>
> Steve Jobs

In this chapter we describe how the evolution of technology has changed the way we communicate and transfer information, completely revolutionizing the concept of storytelling. We analyse the evolution of multimedia tools used for education ranging from multimedia presentations, to simulations, to the use of serious games. We conclude this chapter by analysing the state-of-the-art of serious games developed to address genetics for different types of audience and we try to evaluate their efficacy.

## 2.1 From voice to paper to bits. How technology has changed knowledge transfer

The process of communication has always played a fundamental role from the very beginning of mankind. Humans began to communicate to organize hunting, plan events and forge relationships. Communication allows ideas and information to be transferred using a sophisticated mechanism that converts the ideas of one interlocutor into a form that is comprehensible to the other.

Over time, different techniques have been devised to make communication as effective as possible. Historically one of the tools used to achieve this goal is the use of stories.

Storytelling is the act of sharing stories and information often using improvisation, embellishment or theatrics to increase its appeal. The role of culture is prevalent in storytelling, as each one has its own narratives and stories, used to entertain, educate, preserve it and instil moral values [34].

The earliest forms of storytelling were usually oral combined with gestures and expressions. "With the advent of writing and the use of stable, portable media, stories were recorded, transcribed and shared over wide regions of the world. Stories have been carved, scratched, painted, printed or inked onto wood or bamboo, paper, silk, canvas and other textiles, recorded on film and stored electronically in digital form." [35]

"In addition to its traditional forms (fairy tales, folktales, mythology, legends, fables etc.), storytelling has extended itself to representing history, personal narrative, political commentary and evolving cultural norms. Contemporary storytelling is also widely used to address educational objectives" [36].

The advent of information technology (IT) has introduced a substantial novelty in this field: the possibility to easily interact with contents. Interactivity is a game changer feature for the content fruition of the multimedia era. It could enhance engagement and efficacy and gives users the possibility to set their own peace content exploration.

**Figure 2.1:** *Several approaches could be used to transfer information and knowledge. The advent of technology has opened a new way of knowledge transfer. Interactivity is a game changer feature for content fruition. It could enhance engagement and gives users the possibility to set their own peace in content exploration.*

## 2.2 Genetics concepts

Before going into a detailed description of the various applications developed to address genetics related issues, we decided to include a glossary in Appendix A, that contains definitions for some of the most important concepts of genetics. The Appendix has been written for those who have no genetic background or who would like to refresh these concepts. A review of the terminology will allow the reader to better understand the games and their mechanics that will be described later in this chapter. All the definitions have been taken from the Online Oxford English Dictionary [37] and from the "Learning.Genetics" website [3].

## 2.3 Interactive multimedia to learn Genetics

The National Human Genome Research Institute Meeting Report [38] promotes the use of new media and technologies to disseminate genomic information to effectively engage the public.

One of the most comprehensive English-language websites (Figure 2.2), useful for both students to learn genetics [3] and for teachers to teach it [39], was created at the University of Utah by the Genetic Science Learning Centre.

Through the material published on this website, it is possible to address and study many issues related to genetics, biosciences and health.

For over 20 years, these sites have been providing free multimedia educational material, specifically designed for students and teachers. It is one of the most used scientific website, with tens of millions of visitors

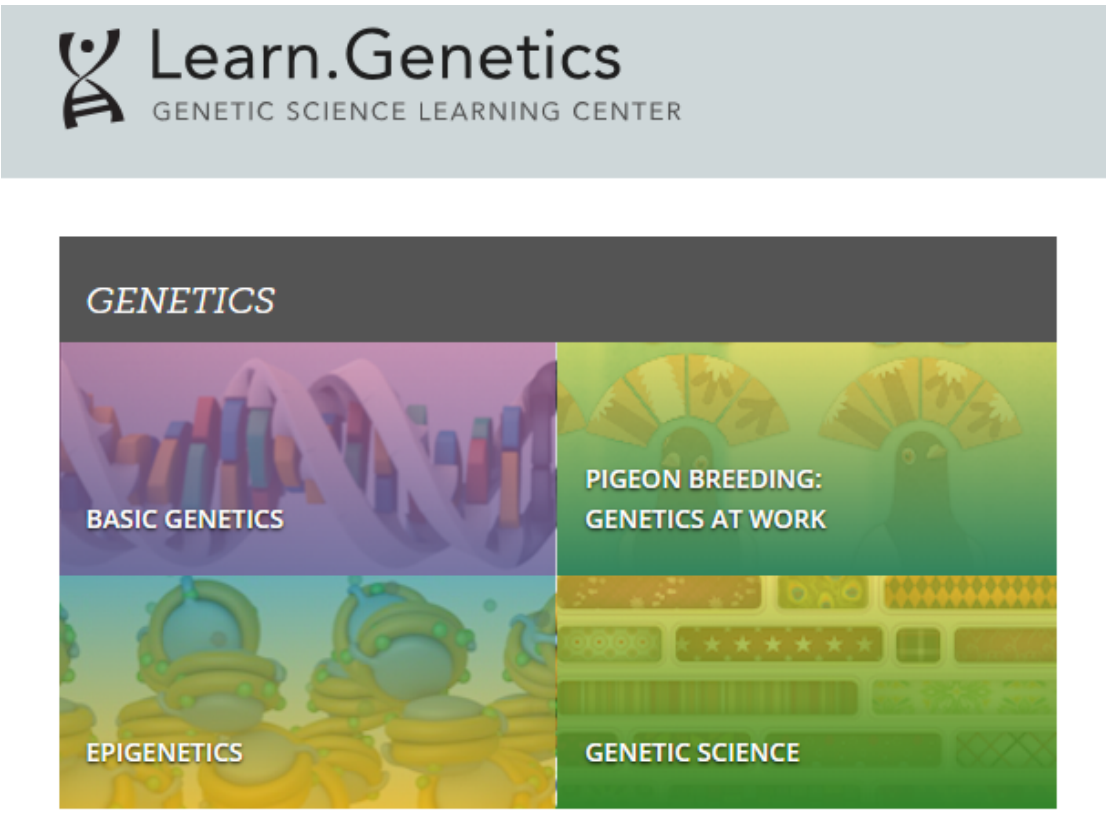


**Figure 2.2:** *The Genetic Science Learning Center, University of Utah, has created one of the most comprehensive English-language websites to learn genetics. Image found on the Web. Retrieved from [3]*

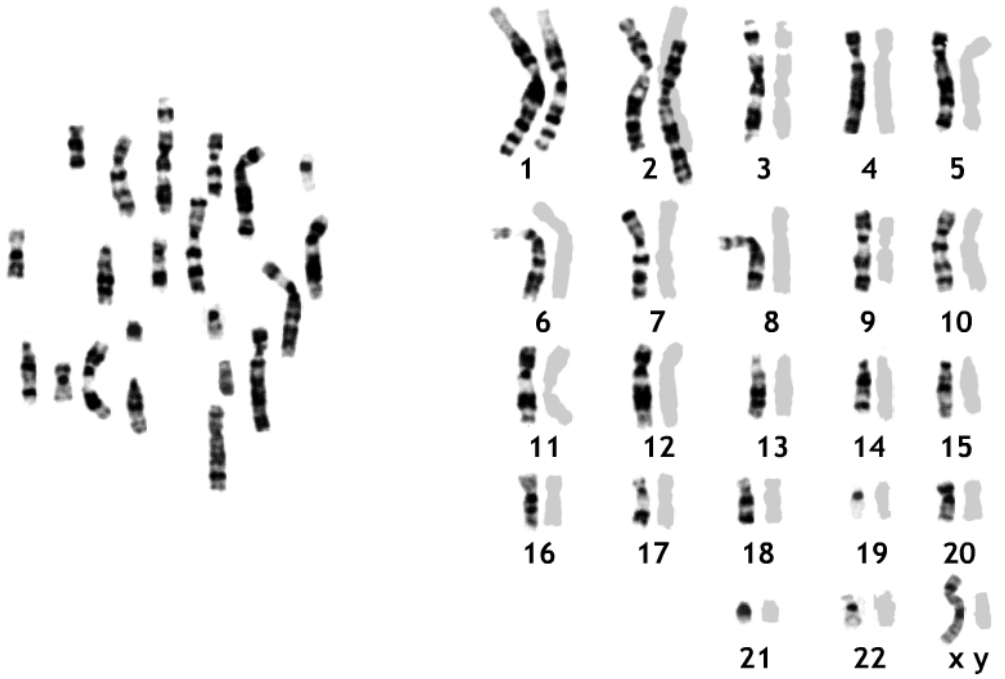


**Figure 2.3:** *The user must click on a chromosome in the pool on the left and drag it next to its partner in the karyotype on the right. There is also the possibility to turn on hints to have an outline of the matching chromosome. Image found on the Web. Retrieved from [3]*

every year. This approach is a perfect example of how to use multimedia interactivity to make learning attractive and functional. The material is produced by scientists who have succeeded in generating texts that are easy and clear to understand, but at the same time rich in content. This collection provides users with material for learning about genetics in various forms, mainly based on texts, images and videos, but among all these "classical modalities", the interactive content really stands out.

Through simulations, the users learn by doing, following tutorials and experimenting with different aspects of genetics. Starting from the most basic theoretical parts, that introduce terminology and explain basic concepts, up to learning to match up chromosomes in a karyotype (Figure 2.3) or playing the role of a pigeon breeder (Figure 2.4) generating new breeds of pigeons, with smooth or ruffled feathers and brown or grey colours.

This resource is very valuable for students and teachers. It has been conceived with students in mind: contents are organized by topic and well defined allowing the website to be easily used during classes. This

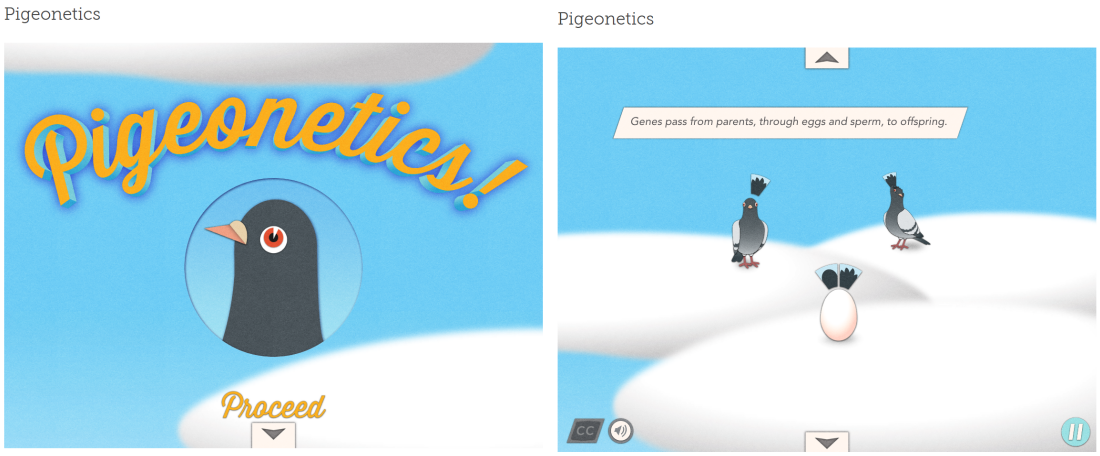


**Figure 2.4:** *In this puzzle game the player, in order to become a good pigeon breeder, needs to know how to pair birds to get offspring with just the right combination of characteristics required. Image found on the Web. Retrieved from [3]*

educational material performs very well on the task it was created for but lacks a playful aspect that allows it to become interesting to the general public who may not be interested in all the didactic details provided by the website.

To have a greater impact on ordinary people the Serious Games (SG) approach (rather than simple multimedia material) seems very promising. SG allows the gamer to proceed according to highly active and multi-linear path modalities, unlike what happens in the classic narrative. It has been shown very powerful in education, training, health promotion, and socialization [40]. SG are a highly interactive medium that can be adapted to the pace of the user, use multiple visual and auditory modes to present information, provide immediate feedback with tailored instructions and encourage experiential learning promoting self-efficacy, goal setting, and cooperation [41].

Our idea is to develop serious games that attract the general public through intriguing game mechanics providing information about genetics, and providing the player with all the information required to understand some issues of genetics. This is done to stimulate and engage the user by testing real-life cases in which genetics and genetic testing could come into play in a person's life. For this reason, SG appears an attractive instrument to popularize genetic concepts to the general public.

## 2.4 Serious Games as the new paradigm to increase genetics literacy and self-efficacy

Computer science, through bio-informatics, was fundamental for the fast growth of the genetics field in the last years. In this thesis, we are going to explore the use of Computer science to develop SG aimed at increasing general knowledge about genetics. We try to speed up the popularization of genetic concepts to the general public leveraging the power and the appeal of SG. This is done to make the general public aware of issues that affect millions of people.

The research question that we address in this work, as stated in the Mind the Risk project [33], is: "Explore new forms of communication and information, and develop tools to improve communication skills regarding genetic risk information".

The SG approach seems to be very promising since it represents a highly interactive medium that supplements traditional educational modalities. In the last years, there have been different attempts to improve individuals' genetic knowledge using different strategies, including the recent implementation of SG (e.g., Touching Triton [6], Geniverse [42], DNA Roulette [4]) which are discussed in the following state-of-the-art analysis (Section 2.5). Unfortunately, current genetic games are mostly addressed to trainees in biology courses and medical practitioners (geneticists), they use very technical language, or they focus on certain aspects of genetics, such as the probabilistic nature of genomics, neglecting the complexity of managing such information for the general public. Nevertheless, to date, there are no available data on the effectiveness of existing SG in increasing people's knowledge of genetic concepts.

## 2.5 Genetics Serious Games – State of the Art Analysis

In this section, we present a detailed analysis of the games discovered during the state-of-the-art review. It was carried out as a starting point to understand which games were already developed in this field and analyse the main features and the audience for which they were intended. Hopefully, we did not leave out any game based on these issues. In some cases the research was quite difficult because many of the games we found were no longer available online, making it hard to perform an

in-depth review of them.

### 2.5.1 *DNA Roulette*

The *DNA roulette* game [4] (Figure 2.5) was released in 2012 at Michigan State University. The game tries to convey to players what a genetic test can reveal and how genes and the environment together define the risk of a person developing or inheriting a trait or a disease. *DNA Roulette* allows players to familiarize themselves with the probabilistic nature of genetics using a procedural approach rather than a narrative approach. Unlike traditional roulette where the odds are always the same, the odds of *DNA Roulette* are different for each disease or trait. Even within a disease, the odds depend on genotypes randomly selected by the game engine for that round.

The game begins by proposing to the player the choice of a trait (e.g. brown eyes) or a disease. The percentage of the genetic factor that influences the development of that trait or disease is then shown to the player. The probabilities in the game are based on real statistics and genetic research. The player is introduced to an imaginary person and asked to bet if at the end of the game this person will or will not develop a trait or disease. The player may choose the amount to bet on the black or red, that represents the fact of developing or not the characteristic or the disease. The game then takes place in four distinct stages:

1. During the first step, the player bets before knowing the odds related to the characteristic or illness of the current match.

2. In the second step, after betting, the player receives more information about the odds of the general population to develop that specific characteristic or disease.

3. In the third step the probabilities of the genetic background of the person initially introduced are revealed and the player is asked to bet one last time.

4. During the last step, the extraction of a roulette colour, which has the probabilities described by the game session, is simulated. The player may then win or lose the amount she has bet.

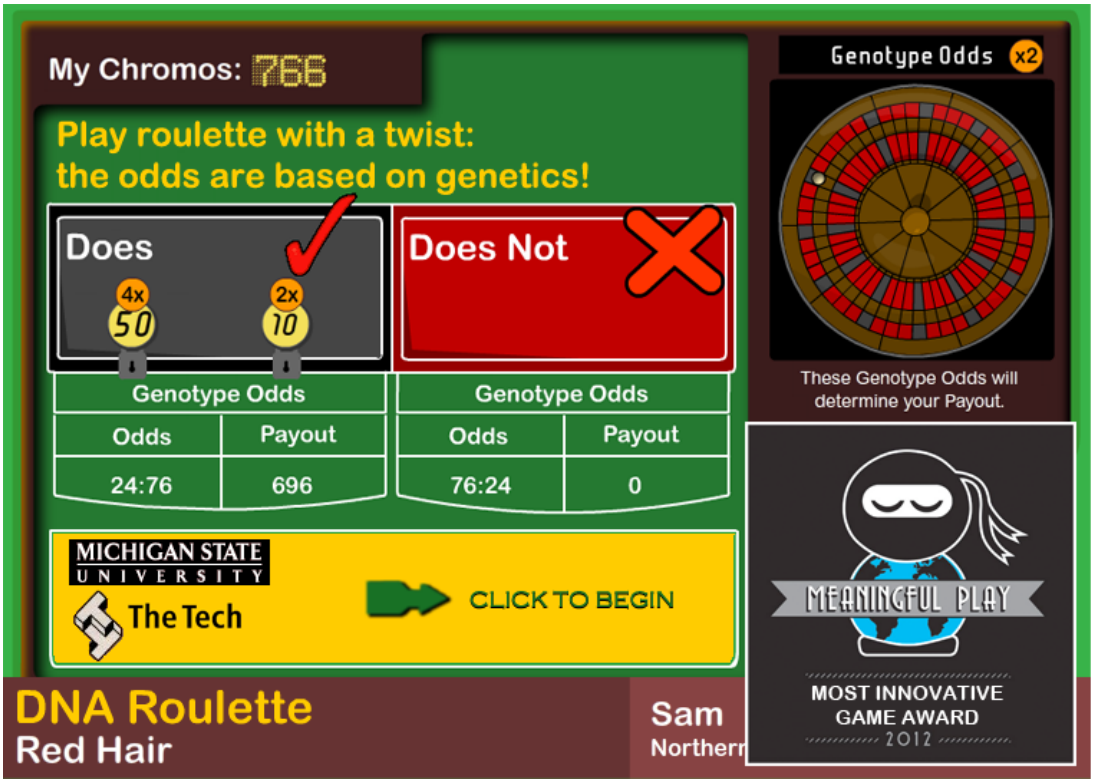


**Figure 2.5:** *DNA Roulette: The player is introduced to an imaginary person and asked to bet if this person will or will not develop a trait or disease. Image found on the Web. Retrieved from [4]*

### 2.5.2 *Niche*

*Niche* [5] (Figure 2.6) is a genetics survival turn-based strategy game combined with simulation and roguelike elements. It was released in 2016 by Stray Fawn Studio on the STEAM platform and represents a perfect example of how it is possible to integrate serious content into a game mechanic, empowering people to understand genetics concepts to succeed in the game.

*Niche* consists of shaping an animal tribe and finding an ecological niche for it to live in. While playing Niche, the player is introduced to the scientific mechanics of genetics (featuring dominant-recessive, co-dominant inheritance, etc.) The player can shape her own species of animals based on real genetics. The challenging part is to keep the generated species alive against all odds, such as predators, climate change and spreading sickness.

**Figure 2.6:** *The goal of the game Niche, consists of shaping an animal tribe and finding an ecological niche for it to live in. Image found on the Web. Retrieved from [5]*

### 2.5.3 British TV station - Channel 4: *Ginger Dawn, Sneeze, DNA Heroes, Breeder*

The Channel 4 British TV station with the Routes Games project has created four exclusive genetically inspired flash games. This project also had the idea of making ordinary people aware of genetic issues. Let's briefly describe the games made for this purpose.

#### *Ginger Dawn*

The world needs more people with red hair. The aim of the game (Figure 2.7) is to help our red hair hero to spread his recessive ginger gene. The player must be able to reproduce with as many women as possible, to keep the ginger population alive within a certain time limit, represented by the rising sun, which forces the player to mate with as many women before he gets sunburns, given the sensitivity of his skin. However, it is possible to get bonus time using sunscreen that protects our protagonist. Although the idea is very ironic, in perfect English humour style, this game has raised several concerns from the public. Some people have in fact understood this game as a matter of eugenics, contesting the fact that authors were promoting an incorrect practice. From the moral point of view, matching the protagonist with as many women as possible could appear as a questionable and sexist practice.

#### *Sneeze*

In this fast-paced game (Figure 2.8) the player must infect as many people as possible with a chain reaction sneeze in different environments and settings. The player has only one sneeze at each level. The player's character is moved to a point of choice in the scene and sneezes. The germs are spread in the hope of infecting as many other people as possible. Although this sneeze does not infect everyone directly, there is a possibility that others may be infected by those who have been infected by the initial sneeze. If the player reaches the target (a certain percentage of people that should be infected in that level), she can proceed to the next level. Although not strictly related to genetics, this game was made available to the public to raise awareness on the issue of contagion.


**Figure 2.7:** *The goal of the game is to help our red hair hero to spread his recessive ginger gene, reproducing with as many women as possible. Screen-shot taken from the game.*

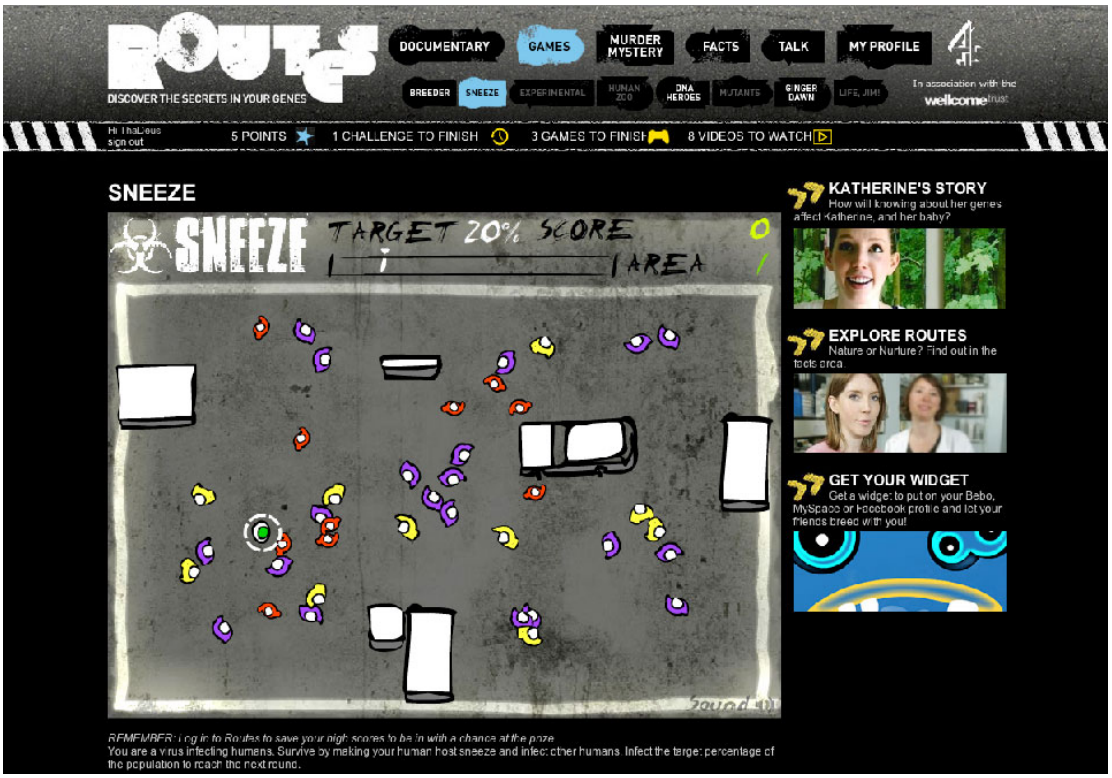


**Figure 2.8:** *In this fast-paced game player must infect as many people as possible with a chain reaction sneeze in different environments and settings. Screen-shot taken from the game.*

*DNA Heroes*

This project (Figure 2.9) is the remake of a famous existing game, Guitar Hero. The gameplay has been modified and requires players to join the combinations of DNA strands and advance through the levels, by rapidly pressing four keys in the correct order and at the right time, in the role of eminent genetic scientists of our time.

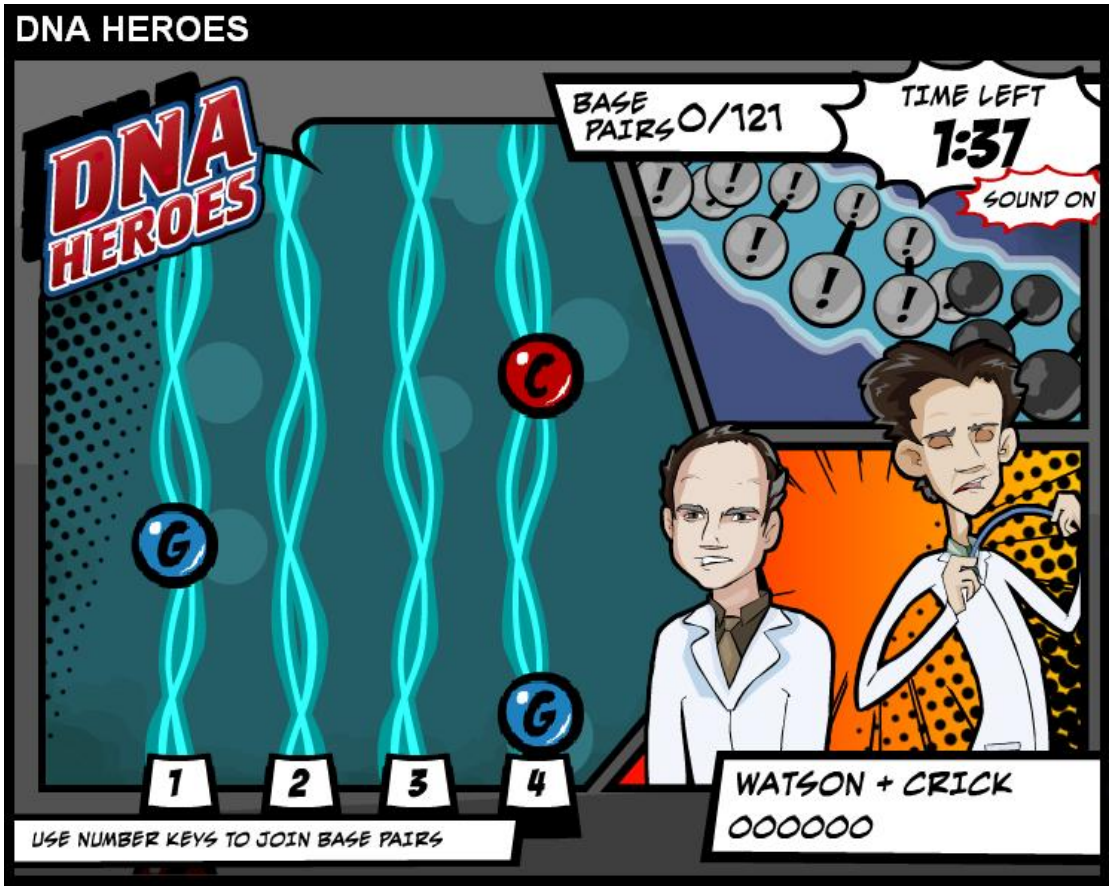


**Figure 2.9:** *Through the rapid press of four keys in the correct rhythm and sequence the player should join the combinations of DNA strands to win. Screen-shot taken from the game.*

***Breeder***

This project is more a simulation than a real game. You can create your own organism and then look for the organism of other players and combine them to get a new breed with the characteristics you wanted. The player has at her disposal a target organism to evolve through different

reproduction cycles, which allows her to appreciate the results obtained and choose the desired reproduction path. (Figure 2.10)

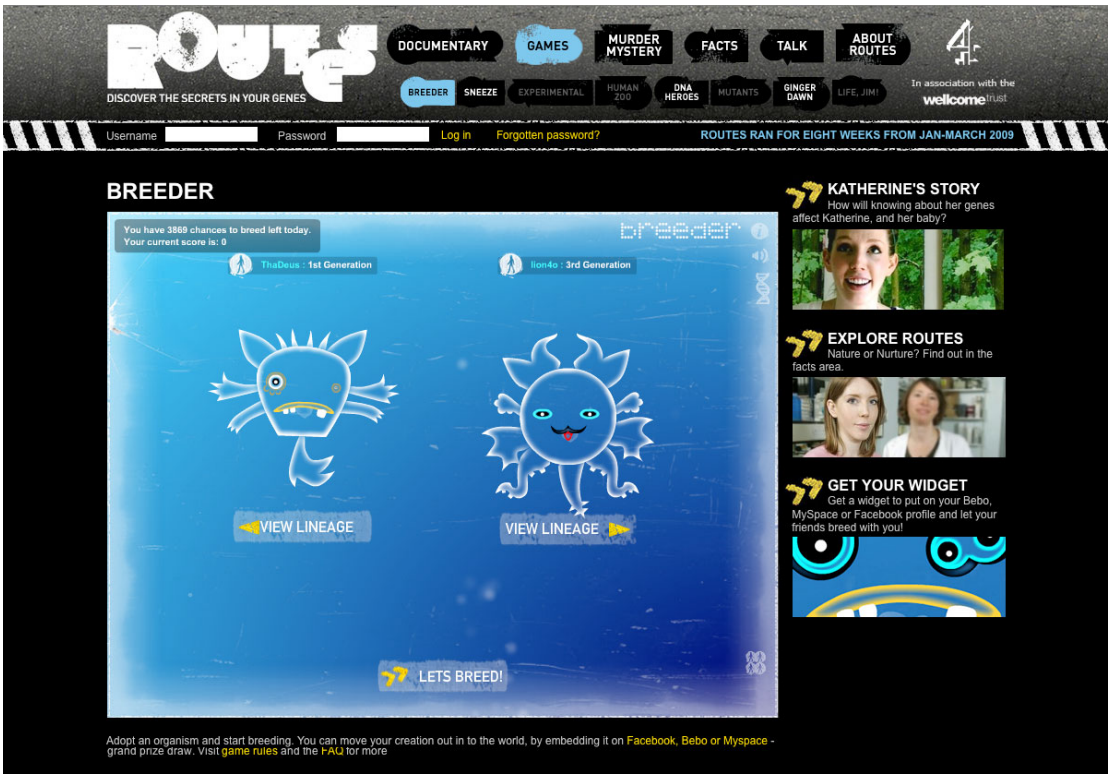


**Figure 2.10:** *In this simulation, the player can create a unique organism and then look for the organism of other players combining them to get a new breed with the desired characteristics. Screen-shot taken from the game.*

### 2.5.4 *Touching Triton*

Developed with the assistance of NASA and the U.S. Space & Rocket Centre, the *Touching Triton* game [6] (Figure 2.11) aims to teach students, enrolled in high school biology courses, to manage modern genomics and health information. The students should keep the six crew members in a 20-year round-trip mission to Triton, a moon of Neptune, alive. The challenge requires players to analyse medical records, genetic and family history data to determine a crew member's risk for six common complex diseases.


**Figure 2.11:** *The player should keep the six crew members in a 20-year mission alive, analysing medical records, genetic and family history data to determine a crew member's risk for six common complex diseases. Image found on the Web. Retrieved from [6]*

### 2.5.5 *Geniverse*

Similarly, the *Geniverse* game [7] (Figure 2.12) engages students in exploring heredity and genetics and it is now freely available to the public. Through a captivating narrative, the game invites the users to breed and study a population of virtual dragons to understand the fundamental mechanisms of heredity and genetic diseases.


**Figure 2.12:** *The game encourages users to breed and study a population of virtual dragons in order to understand the fundamental mechanisms of heredity and genetic diseases. Image found on the Web. Retrieved from [7]*

### 2.5.6 *DNA-The double helix*

The *DNA-The double helix* [8] (Figure 2.13) starts with an introduction to different concepts of genetics, highlighting how the nitrogenous bases (A-T-C-G) always bind with a specific nitrogenous base: Adenine with Thymine and Cytosine with Guanine. The game develops in two different steps: in the first one the player must complete the exact copy of a double-stranded DNA by correctly matching organic bases pairs; in the second one where the player must choose which organism this genetic material belongs to, according to genetic information given during the

first phase of the game, such as the number of chromosomes or the number of genes.

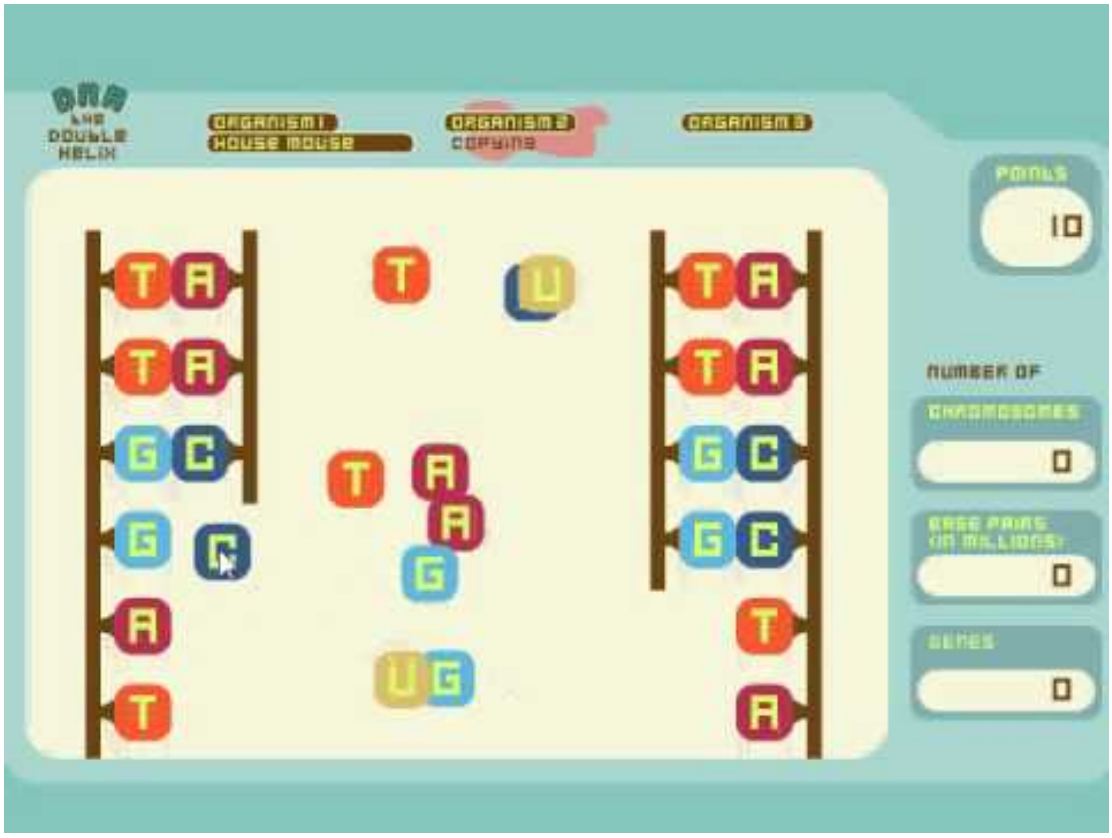


**Figure 2.13:** *The player has to complete the exact copy of a double-stranded DNA and has to associate it with the right organism. Image found on the Web. Retrieved from [8]*

### 2.5.7 *PaJama*

*PaJama* [9] (Figure 2.14) is an HTML5 game simulation of fishes breeding based on the fundamental heredity laws. (The game is no longer available, and these were the only information found)

### 2.5.8 *Angel Breed*

*Angel Breed* (Figure 2.15) is a serious educational game developed by Play three in collaboration with Open University.

The game is designed to bring older populations closer to higher education courses at Open University, particularly to those related to genetics.

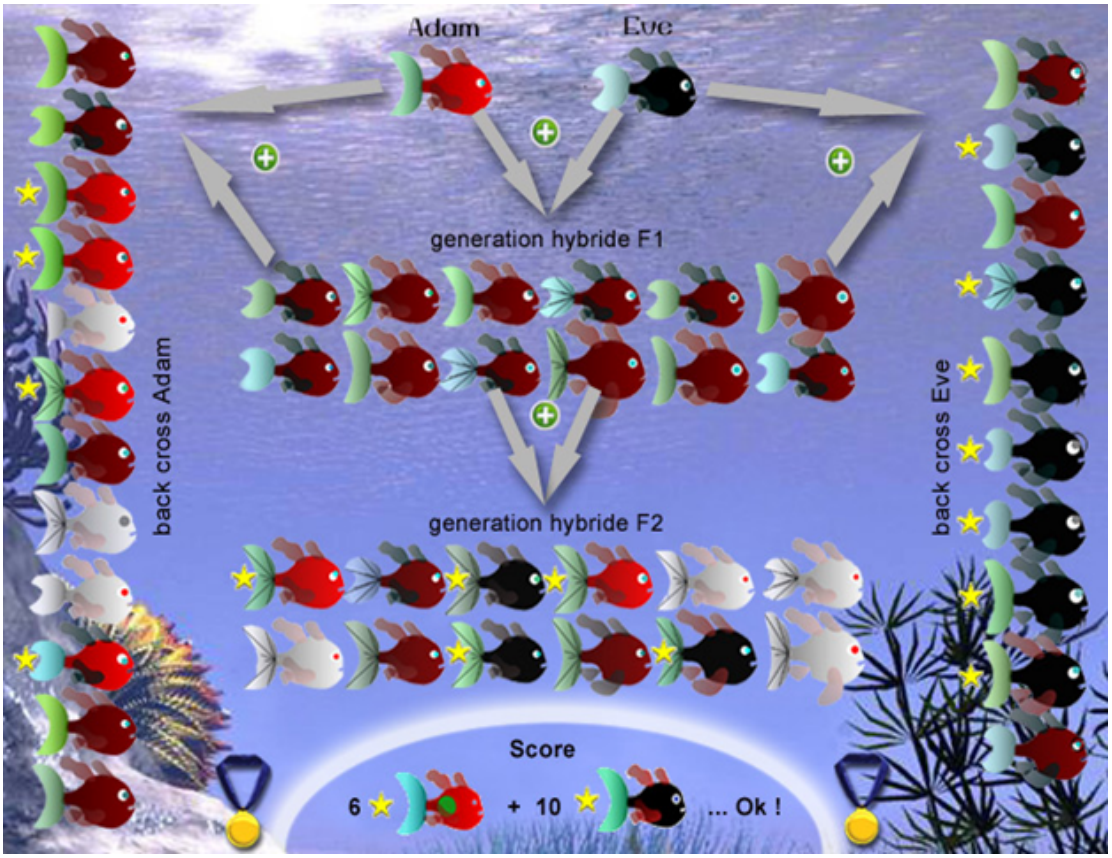


**Figure 2.14:** *Pajama game is a simulation of fishes breeding based on the fundamental laws of heredity. Image found on the Web. Retrieved from [9]*

The aim of the game is to raise as many "high value" fish as possible in a limited number of shifts (spawning cycles). The genetic value map of each fish is generated according to the rarity of its phenotype. Random breeding will produce a lot of variety, but the real way to success is to understand the genetic breeding process that occurs, trying to produce fish with rare characteristics and then reselling them to earn money to buy even more valuable fish.


**Figure 2.15:** *The player should try to produce fish with rare characteristics and then resell them and earn money to buy even more valuable fish. Screen-shot taken from the game.*

### 2.5.9 MD-Bio

"MdBio Foundation is a non-profit organization that provides effective, experiential and innovative education focused on bioscience. The teaching approach is interdisciplinary and uses Science, Technology, Engineering, and Mathematics (STEM) to explore real-world, problem-centric learning that bridges school, community, health, and business" [43]. MdBio has developed an immersive learning environment called *MdBioSphereTM*, a collection of serious video games covering a wide range

of biology topics while incorporating mathematics, chemistry and other interdisciplinary content.

The "Survival" project is presented as a valuable tool for genetics learning in high schools. Survival integrates a series of educational mini-games that test a student's competence and provide milestones for teachers. The topics covered in Survival have been identified by high school teachers as subject areas that are particularly challenging for students.

The two games accessible from their web page are:

- *Sorting Genetics*
- *DNA Mutations*

#### *Sorting Genetics*

*Sorting Genetics* (Figure 2.16) can be used to practice genotype and phenotype. The game consists of classifying air bubbles that rise from the bottom of a pond and contain within them a genotype. On the surface of the water, there are three wood holes each with a label (e.g. homozygous dominant and recessive, heterozygous). The player must correctly classify the bubbles by dragging them into the correct hole to get bonus points.

#### *DNA Mutations*

The aim of the *DNA Mutations* game (Figure 2.17) is to find the differences between the wild-type and mutant fish DNA. The player must select the nucleotide of the wild-type DNA that is different in the mutated fish. The player must then specify the type of mutation (e.g. added, deleted or substituted). If the player guesses correctly, then she earns points and adds the fish to her aquarium.

### 2.5.10 *Thingdom*

In the *Thingdom* game [10], you need to take advantage of the Mendelian laws to generate an offspring with a particular feature. The characters with which the player can interact through the mouse are "Things". The player can move them, caress them and make them play, like a sort of Tamagotchi (Figure 2.18). These actions lead the "Thing" to grow and

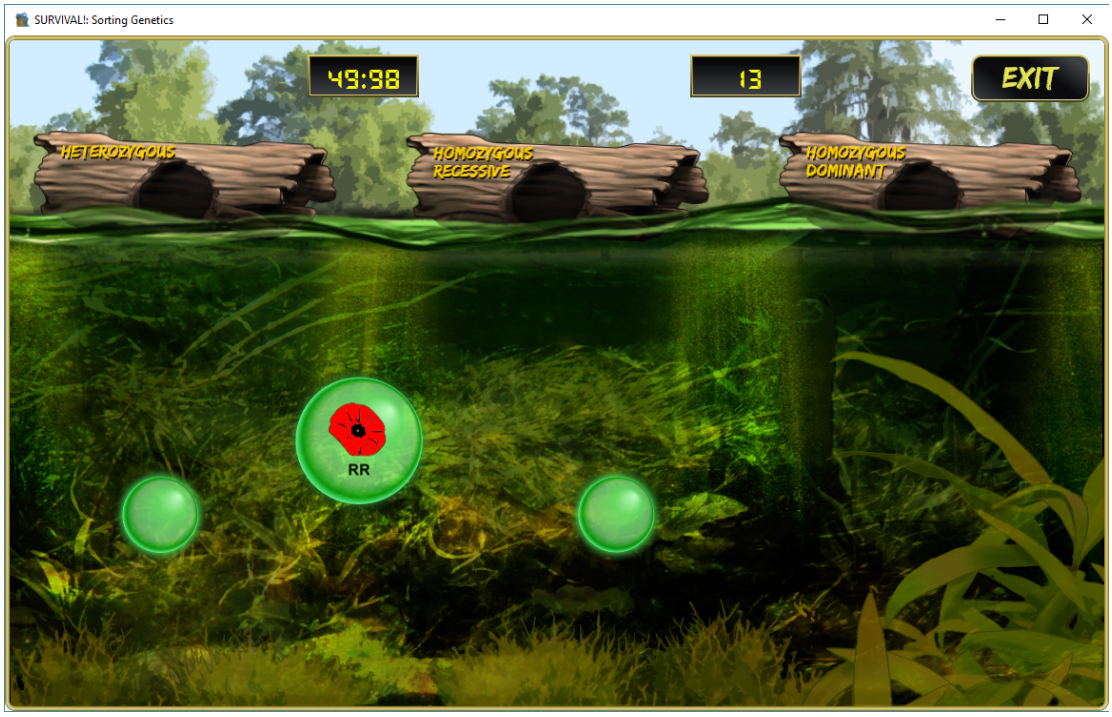


**Figure 2.16:** *The player must correctly classify the genotype contained in the bubbles by dragging them into the correct hole to get bonus points.*

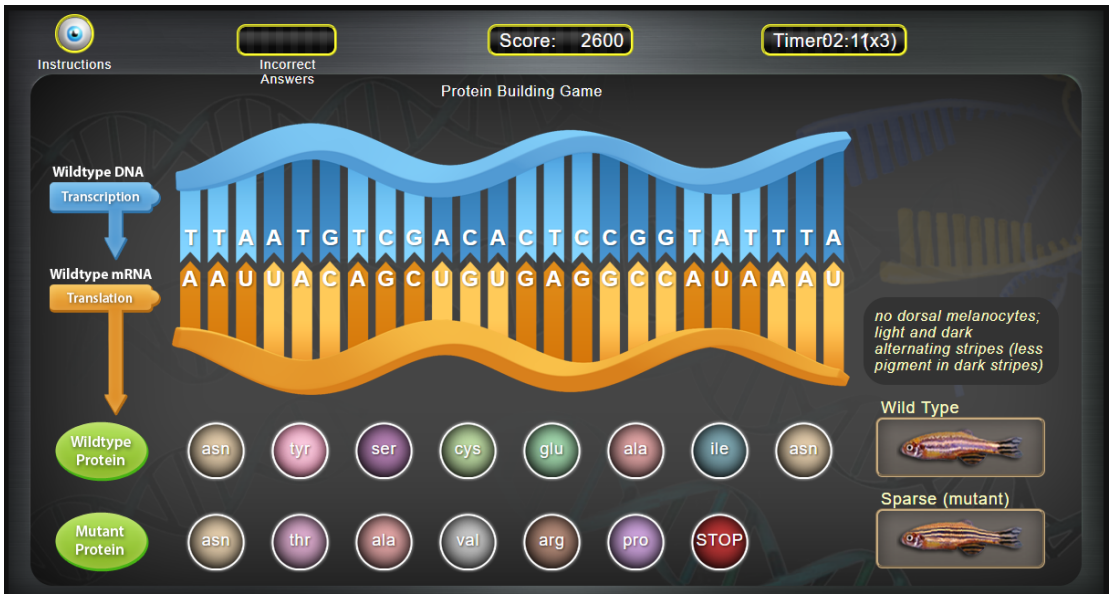


**Figure 2.17:** *The player must specify the type of mutation expressed in the DNA of wild-type fish (e.g. added, deleted or substituted). Screen-shot taken from the game.*

move from children to adults. Once they grow up they can reproduce with other "Thing", the aim is to identify in the other "Thing" the characteristics required to win the game through the next generations.


**Figure 2.18:** *In this game, the player can interact through the mouse with the "Things" like in a sort of Tamagotchi and make it grow and reproduce with other "Thing" to achieve the characteristics required to win the game through the next generations. Image found on the Web. Retrieved from [10]*

### 2.5.11 *Dragon Breeder*

In the *Dragon Breeder* game [11] the player applying the concepts of Mendelian genetics must be able to generate new dragons with well-defined genetic characteristics or use the phenotype to discover the possible genotype of the dragon (Figure 2.19). The game can be played in two different modalities: Free play and Campaign. In the first modality, the player can advance in the game by matching the dragons and reselling them to earn money. In the campaign mode the player can perform missions that lead her to learn about particular genotypes of the dragon and more information about the island on which the game is set.

### 2.5.12 *Transcription Heroes*

*Transcription Heroes* [12] is another remake of the famous Guitar Hero™ game. As in *DNA Heroes*, the user presses four keys representing the ni-


**Figure 2.19:** *The player applying the concepts of Mendelian genetics must be able to generate new dragons with well-defined genetic characteristics. Image found on the Web. Retrieved from [11]*

trogenous bases and must reconstruct the DNA presented on the screen at a relentless pace (Figure 2.20). In this game, player can also play using the hardware controller in the shape of a guitar, produced for the original Guitar Hero™ game.

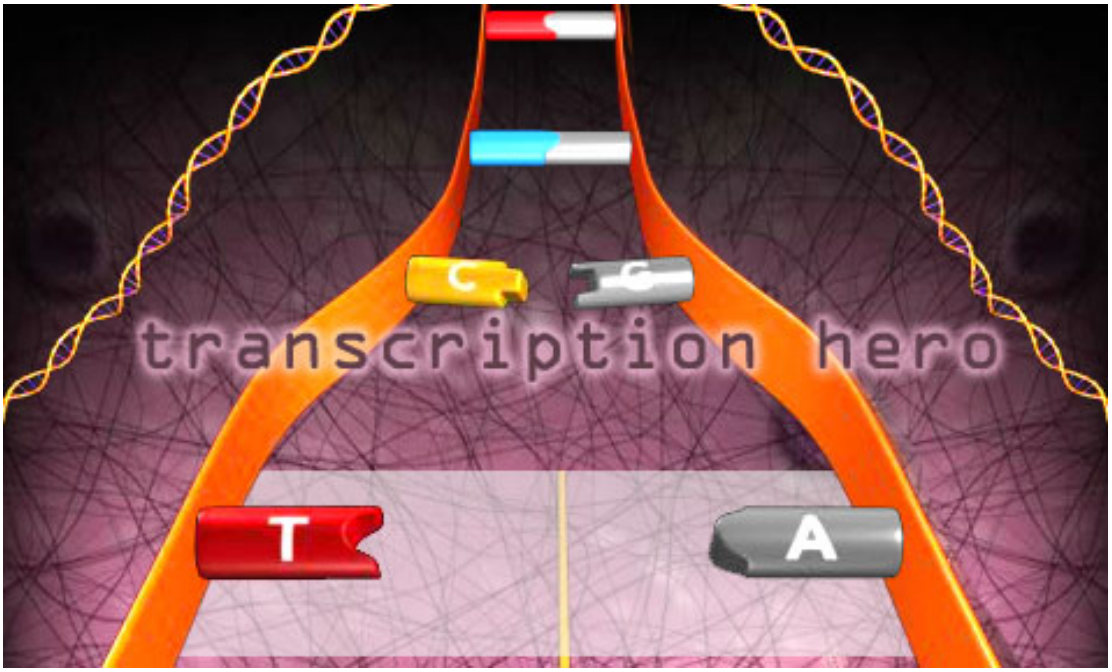


**Figure 2.20:** *In Transcription Heroes, the user presses four keys, representing the nitrogenous bases, and must reconstruct the DNA. Image found on the Web. Retrieved from [12]*

## 2.6 Are these games feasible for the general public?

From our analysis of the state-of-the-art of genetics related SG, four macro thematic categories to classify games have been identified:

- ***Genetic risk and probability***
  - DNA Roulette
  - Touching Triton
- ***Heredity and Mendel's laws***
  - Niche
  - Ginger Dawn

  - Breeder
  - Geniverse
  - PaJama
  - AngelBreed
  - Thingdom
  - Dragon Breeder
  - Sorting Genetics

- ***Mutation***
  - DNA Mutations

- ***DNA transcription***
  - Transcription Heroes
  - DNA Heroes
  - DNA-The double helix

Most of these games are very interesting and cover several fundamental genetics basic concepts which are useful to understand more complex topics.

However, we have noticed that most of these games provide basic notions of biology more adequate to an audience of students rather than the general public. And if in some cases the games have been developed specifically for lay people, such as Ginger Dawn, the information that is provided is always very specific and limited to a well-defined topic, leaving aside a fundamental aspect: how genetics impacts our lives and how today it is sometimes possible to make use of the results of genetic testing as a decision support tool for healthy choices.

We strongly believe that a basic knowledge of certain concepts of genetics is fundamental to understand more structured and complex concepts. For this reason, part of our contribution has been to try to identify the basic notions of genetics that we believe to be the pillars on which to develop more complex concepts (this is discussed in detail in chapter 5, sections 5.2.1 - 5.3 - 5.3.1). Additionally, we want players to experience the feelings perceived while undergoing genetic testing.

## 2.7 Games for Learning: an evidence-based approach

"An evidence-based approach to the study of games for learning involves using appropriate research methods, grounded in learning theory, to yield data needed for answering testable questions" [44].

Every year, several SG are developed in the medical field. However, there are few cases in which their usefulness and effectiveness are scientifically proven.

Demonstrating that a SG is able to achieve his goal, is the best way to carry out research on these issues. Gathering and accumulating information on the experiments, allows us to discard constructs or practices that do not work and focus our efforts on what seems to work [44].

Several studies [45]- [46] have been carried out to try to formalize strictly scientific tools and methods that allow the development and the evaluation of SG following standards that, if followed, ensure the creation of valid SG.

Referring to the state-of-the-art games described, the most relevant aspect is that none of the games mentioned so far, except "Touching Triton" [6], has been tested to understand whether it is an effective learning tool.

"Touching triton" turns out to be the only game to have been tested with regard to its effectiveness as an educational tool. As described by the authors in the paper [6], the game was tested on an important sample of students, proving to be a valuable tool for learning and succeeding, able to involve students in a powerful way.

These results reinforce our belief that SG are an appropriate tool for achieving the intended purpose. However, the limit found in this study, compared to what we want to try to prove, is the population involved.

This experiment has been carried out on students of a course in biology, young people fresh from studies and accustomed to the use of new technologies. On the contrary, what we would like to try and demonstrate is to validate the SG developed for the general public, thus including a more heterogeneous population.

This is perhaps the most important reason that prompted us to design, develop new games and re-implement some mechanics of arcade games, instead of reusing games already developed by others, which without the

source code could not be modified and re-adapted. Writing the source code gave us the flexibility to test them and make changes to the games after evaluating their playability and effectiveness, to better adapt them to their educational purpose.

CHAPTER 3

# Serious aspects

> Children's games are hardly games. Children are never more serious than when they play.
>
> Michel de Montaigne

"Although all games are in some way educational, the games in this set are designed with explicit educational goals in mind" [47].

Let's start this section with an introduction about SG by analysing some of the most famous definitions provided by the experts in the field. After a brief discussion of the history of serious games, we analyse the fundamental aspects of our mind related to the learning process. We introduce the psychological theories typically applied to a particular category of serious games: games for learning. These are games which have as their main objective the improvement of the knowledge and cognitive abilities of players.

## 3.1 Serious Games Definitions:

The Serious Game term was probably first used by Clark Abt, a developer of military computer games, in 1971. In his book "Serious

Games" [48], the U.S. researcher provides a definition of educational games, regardless of the medium (digital or real-world). He describes them as games with an explicit and well-structured educational purpose, not primarily intended for fun, but not excluding it.

A more modern and general definition has been provided by two game designers: Sande Chen and David Michael who call the serious game a "game whose main purpose is not entertainment".

However, nowadays, the term SG describes mainly educational video games as the widely used definition by Sawyer suggests: "any meaningful use of computerized game/game industry resources whose chief mission is not entertainment" [49].

A more specific definition has also been provided by Professor Michael Zyda, Director of the USC GamePipe Laboratory, which defines SG as: "A mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives". Starting from these definitions we can, therefore, say that SG are digital games that do not have exclusively or mainly a purpose of entertainment but contain educational elements. Generally, SG are educational tools were ideally **serious and playful aspects are balanced**, but often even the only interactive virtual simulation is considered a serious game. The core of the SG is the desire to create an effective and enjoyable educational experience and is therefore difficult to find a clear distinction from entertainment games because it is often the use of the player herself that determines the educational aspect. SG have the fundamental purpose of developing skills and competencies to be applied in the real world through exercise in a simulated and protected environment.

## 3.2 Why are Serious Games so powerful?

Animals and humans learn through play and through play they develop a sense of mastery, a sense of competence in doing several tasks. "A game is an artistically simplified representation of a phenomenon" [47] and through games it is possible to recreate a protected environment, a place where the user can improve certain behaviours, certain skills that

are reflected later in everyday life: she will remember how she dealt with the situation within the video game and will be able to find the best solution that she has managed to adopt within the virtual environment.

In 1982 Chris Crawford, one of the pioneers of video game programming, suggested that there are four fundamental elements in a video game: representation, interaction, conflict and salvation. [47]. According to Kasvi, the combination of these four factors gives rise to "a closed formal system that constitutes, subjectively, a cross-section of reality". The Interactivity of the media allows programmers to adequately represent the randomness that governs aspects of reality that are subject to change. As a result, "the player can explore the reality of the game." [50].

The opportunity to live some experiences in a virtual environment can be of great help to people: every day millions of people play video games that recreate situations of everyday life that are sometimes appropriately modified to adapt to the constraints dictated by the game design.

The games also allow the repetition with experimentation. You can try and try again, learning from mistakes. "The videogame is a didactic device, a machine to learn. While society punishes the error, the videogame encourages it. Making mistakes is part of the game. The videogame is a Buddhist exercise. It teaches you to die ten, a hundred, a thousand times" [51].

### 3.2.1 Learning through Serious Games

Learning can be viewed both as information acquisition and as knowledge construction, that is the ability to use the new knowledge. Individuals' ability to properly act in a given situation depends both on the knowledge they have acquired, and on their ability to "transfer" that knowledge in the situation they are actually in [52].

Before analysing how it is possible to learn through video games, it is useful to try to formalise the multimedia learning process in the human being, highlighting the salient aspects derived from the use of new multimedia tools.

## 3.3 Relevant Psychological theories about Learning

Let's explore on what theoretical bases the development of this type of games is based. It is possible to highlight the presence of two macro areas. The first, which we will deal with in this chapter, is composed of the psychological theories addressed to the most serious part of the experience, the one related to learning. The second one, which is common to most games, is addressed to the motivational and experiential aspects of the game, which will be described in the next chapter, dedicated to good game design techniques that, by implementing some famous psychological theories can turn a game into a really exciting and engaging experience.

### 3.3.1 How people learn? The Cognitive theory of learning

A fundamental part of the Science of learning, that is the scientific study of how people learn [53], is the system for processing human information, used by every human being in the learning process.

If we think about classic learning process resulting from reading texts, as happens most of the time in the academic context, the visual/pictorial information is acquired through the visual system, selected and processed in the working memory by the brain and integrated and organized with the prior knowledge, present in the long-term memory.

Learning occurs if significant active processes occur. By active processes, we mean being able to identify and isolate material relevant to the subject matter, the mental organization of the contents acquired in coherent representations and finally the integration of the contents with the relevant prior knowledge [54]- [55].

The learning process performed through multimedia tools operates similarly to traditional learning, but, in this case, the channel of information acquisition is no longer limited to the visual/pictorial one, but the auditory/verbal channel is also involved.

In this situation, our brain is required to process both channels and to align and integrate the two flows. The human being, in fact, has separate channels to process auditory/verbal material and visual/pictorial material [56]- [57]. However, our central nervous system is only able to actively process a small amount of the information we acquire through the

sensory channels [58]- [59]- [60]- [61].

The human body is provided with three types of memory:

- Sensory Memory
- Working Memory
- Long-term Memory

The amount of information acquired through the eyes and ears (Sensory Memory), kept in the form of a sensory signal is very high but lasts a few moments (e.g., a quarter of a second). The information selected by the Sensory Memory is transferred to the working memory where it is processed and converted into verbal and pictorial representations. These representations can be mentally manipulated but only a small part of them can be processed for an instant of time. These limitations lead to a reduction in the capacity of the cognitive processes that take place within the working memory. In fact after about 20 seconds the material acquired by the Sensor Memory decays if it is not actively processed.

Once the acquired information has been actively processed, it is stored in the long-term memory, which, if optimally organized, guarantees almost unlimited storage capacity. In this process, it clearly emerges that among the three types of memory, the one that represents the bottleneck for learning through the multimedia material is the working memory, as highlighted in Figure 3.1.

This analysis led Mayer to state that: "This structural feature of the human information system has crucial implications for learning with games, because it is easy to overload the game player's working memory, thereby decreasing the opportunity for making sense of the material" [44].

It is therefore essential during the development of games for learning, to pay particular attention to the game mechanics that are going to be developed. It is necessary to design game features that promote motivation to learn but at the same time do not break the cognitive processes involved in learning.

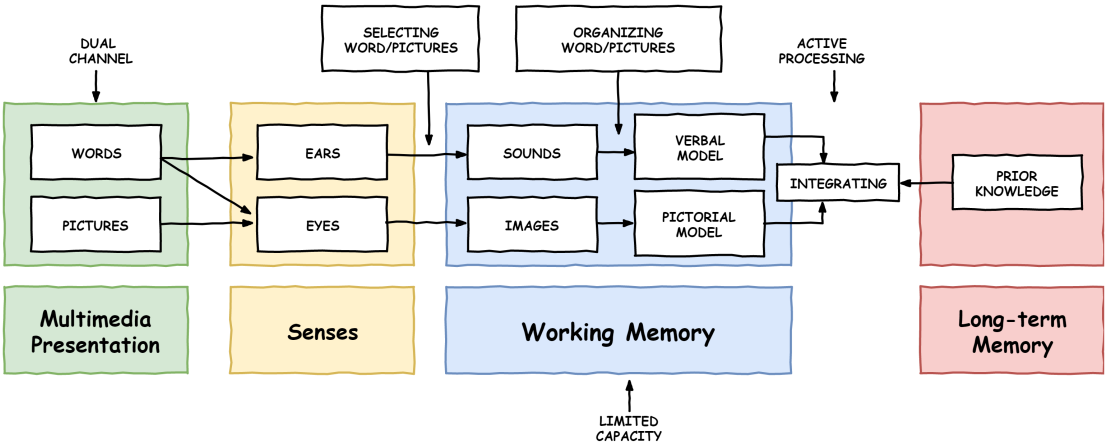


**Figure 3.1:** *A cognitive theory of multimedia learning: people process auditory/verbal vs. visual/pictorial information through different channels. The limited ability to process this multi-channel information is the bottleneck of the whole process. Learning happens if people have adequate cognitive processes.*
*Representation of "The Cognitive Theory of Multimedia Learning" by Richard E. Mayer*

### 3.3.2 The Self-Efficacy Theory

We have analysed the pillars on which the cognitive theory of learning is based, but there are many other psychological theories that come in handy during the design and testing phases of games for learning. Mayer, in his book [44], proposes several psychological theories that should always find their place in the design and testing of games for learning. In fact, according to the author, it is very important to understand how the human mind works to be able to introduce the best elements into the game that can promote learning processes. A very important theory, that could be used to evaluate if people are going to learn better in games for learning is the Self-efficacy theory.

#### What is self-efficacy?

Self-efficacy is a cognitive process identified by social psychologist Albert Bandura for the analysis of human agency [62]. The theoretical context within which this construct develops is a cognitive social theory.

At the core of social cognitive theory, there are all the thoughts that affect human functioning, and standing are self-efficacy beliefs, "people's judgements of their capabilities to organize and execute courses of

action required to attain designated types of performances".

Self-efficacy can be defined as a generative capacity, the function of organising particular elements whose purpose is to orient individual cognitive, social, emotional and behavioural sub-abilities in an efficient way to fulfil specific purposes.

Self-efficacy beliefs deeply influence motivation, well-being, and personal accomplishment. If people believe that their actions can produce the desired outcomes, they are motivated to act or to persevere in the face of difficulties.

Many factors influence human functioning. The knowledge and skills they possess will play critical roles in what they choose to do and not do. Individuals interpret the results of their attainments, however, just as they make judgements about the quality of the knowledge and skills they possess.

#### Do people with high self-efficacy learn better?

The self-efficacy theory has been verified in several studies. In the study conducted by Schunk [63], it is shown that students who have high self-efficacy with respect to the task of learning arithmetic actually learn better than students who have low self-efficacy with respect to the same task. Similarly, in another study proposed by Chemers [64] students who believe that their first year of college will be fine actually get better grades than students who think otherwise.

Let's try now to decline this theory in the field of games for learning. As mentioned in the definition of self-efficacy, if the player is convinced that she can succeed in a learning task (she has a high self-efficacy towards that task) she will most likely be able to persevere even when she encounters difficulties and will work more intensively to try to solve them. On the contrary, if the player believes that she is not able to tackle a learning task (she has low self-efficacy towards that task) she will most likely not persist in trying to master the material and will abandon the learning task.

The use of serious games, however, acts through two different self-efficacy modalities. Firstly, the learning task is hidden within a game, where elements of the self-efficacy theory could be implemented [65]. In this way the task is not presented to the player as a pure learning task

and the player is less critical about it. Secondly, if the game manages to achieve its purpose, which is to transfer knowledge to the player, most likely at the end of the game session the player will feel more confident about the subject matter and this will also likely lead to an increase in self-efficacy for that task. This last aspect is very important in case the training process does not end but must continue over time, increasing the amount of information and the difficulty of the task.

## 3.4 Games for Learning

In the previous paragraphs, different definitions of serious games have been provided. In this section, we try to provide a more specific one for the kind of serious games that have been developed during the MTR project: games for learning.

The fundamental elements of games for learning are provided by Mayer in his book "Computer Games for Learning: an evidence-based approach" [44].

Mayer claims that games for learning must have a specific characteristic to be defined as such: they must cause a measurable change in the player's knowledge or cognitive abilities, in fact, "the gold standard in game effectiveness research is to measure a change in what the learner knows or can do" [44].

Games for learning can be based on games and simulations that can be played both in reality and through the use of a computer. In this type of serious games, the serious part deals with providing players with relevant material related to the field of training, helps them to mentally organize this information through a consistent cognitive representation and integrate them with previous knowledge related to the subject.

## 3.5 The right mix of serious and game

We have introduced the theories on which the serious part of games for learning is based, but, as indicated by the name itself, in addition to the serious part, the gaming aspect should be present and equally balanced. The gaming part deals with keeping a high level of attention, interest on the topic and motivating the user to continue the game. In the next

chapter, we try to outline the psychological theories that are typically implemented in games during the game design phases.

CHAPTER 4

# Gaming aspects

Waka waka waka, waka waka!
"Waka waka?" Waka.

Pac-man

Over the years, countless research and experiments have been carried out by experts (e.g. psychologists, sociologists, philosophers, game designers) to try to understand and formalize the ineffable and unique nature of games. These studies try to understand the characteristics that leverage the instincts and needs of human beings, managing to generate a unique gaming experience which is exciting and rewarding for the player.

After having dealt with the basics of the psychological theories on which the serious part of games for learning are based, we introduce the concepts and psychological theories that, if implemented, can make a game motivating and fun. These characteristics are required to keep the player focused and to encourage her to continue playing in order to make her enjoy all the educational content in an active and fruitful way. This applies to all kind of games, including video games which are the focus of our research.

Let's try to ask ourselves the following questions: why do we play

video games? What drives us to spend hours and hours of our time destroying alien spaceships, collecting coins and saving princesses? Years of research are beginning to bear fruit. We are now able to grasp some of the aspects that make a game a highly motivational experience.

Creating a video game that is both interesting and fun is not a trivial task, furthermore, it becomes even more complex if there are constraints on the content and on the way it should be treated, as in the case of serious games. The field of game design is still young and, in many ways, unexplored; many researchers are still trying to understand and refine the elements that make a game good [66].

Over time, some of the features that are universally recognized by game designers, have been identified as fundamental aspects of a game, even though they are not required to be all included at the same time. For example, a game typically has rules that must be followed by the player to achieve the objectives and obtain results. Usually, there is a storyline that guides the player through a story. The player can interact within an environment, receiving feedback depending on the taken actions. Another important feature is given by the competition that pushes the player to play at her best. Games usually have features that make them immersive and interesting for the player. All these characteristics, however, have been formalized over time with different psychological theories that try to give a formal explanation of why these aspects are so appreciated and sought after by human beings.

## 4.1 Motivation: Internal and External

The most striking aspect of a well-made game is its ability to motivate the player and push him to play for many hours.

Motivation can be defined as the set of factors that push an individual to make certain choices and take an action. Psychological studies have formalized two distinct types of motivation: internal and external. In internal motivation what drives one to take an action or to keep doing it over time comes from within: from a desire, from the pleasure perceived while performing that action. External motivation is triggered by an external reward and is typically used to make people perform tasks that they would not normally want to do.

In video games typically, the elements that generate internal motivation are fun, challenge and immersion. These characteristics make internal motivation much more effective than external motivation, which is typically stimulated in video games through external achievements that, for example, allow players to gain popularity through a leaderboard (social status).

Compared to the external motivation, internal is more long-lasting, self-sustaining and fulfilling. In fact, as demonstrated by Ryan and Deci [67], people who act because they are internally motivated achieve better performance, persistence and creativity, heightened vitality, self-esteem and general well-being.

## 4.2 What makes games fun?

Well-structured games provide a very powerful motivational element: fun. Let's try to understand if it is possible to define or at least identify the elements that contribute making a game "*Fun*".

Let's start by defining the concept of "*Fun*" in two dimensions:

- Engagement: "The willingness to have emotions, affect, and thoughts directed toward and aroused by the mediated activity in order to achieve a specific objective" [68].
- Enjoyment: the state or process of finding pleasure in doing something.

These two dimensions are closely linked but they are two different things. When the player encounters these two dimensions in a game, she will feel motivated to play and continue; let's now detail the concept of motivation, analysing the characteristics that make up a game.

As widely discussed in Pirovano's doctoral thesis [69], several scholars have explored the concept of "*Fun*" over time. Among those the most significant are:

- Malone [70] identifies three highlights that according to him make a game an enjoyable activity and are:
  1. Fantasy

2. Challenge
3. Curiosity

- Hallford & Hallford [71] analysed and categorized four types of internal rewards:

  1. Glory
  2. Access
  3. Sustenance
  4. Facility

  This classification was made according to the effect that each reward had on the gaming experience evaluated along the study.

- Salen & Zimmermann [66] highlight how the concept of "pleasure" cannot be reduced to a single element but is formed by a set of factors.

- Hunicke et al. [72] explain how the vocabulary used is too limited to describe the aesthetics of a game and propose to introduce the following taxonomy which enriches the concept of "*Fun*":

  1. Sensation: Game as sense-pleasure
  2. Fantasy: Game as make-believe
  3. Narrative: Game as drama
  4. Challenge: Game as obstacle course
  5. Fellowship: Game as a social framework
  6. Discovery: Game as uncharted territory
  7. Expression: Game as self-discovery
  8. Submission: Game as pastime

- Bartle [73] has studied how different kind of players approach a game, observing the "inter-relationship of two dimensions of playing style: action versus interaction and world-oriented versus player oriented." These playing styles led him to define four different types of players:

1. Killers: “interested in doing things to people.”
2. Achievers: “interested in doing things to the game.”
3. Socialisers: “interested in interacting with other players.”
4. Explorers: “interested in having the game surprise them.”

- Lazzaro [74] has measured and classified players according to their visceral, behavioural, cognitive, and social responses to games, and proposes four keys that unlock different emotions:

  1. Hard Fun: “Players like the opportunities for challenge, strategy, and problem-solving...this “Hard Fun” frequently generates emotions and experiences of Frustration, and Proud.”
  2. Easy Fun: “Players enjoy intrigue and curiosity...these immersive game aspects are “Easy Fun” and generate emotions and experiences of Wonder, Awe, and Mystery”
  3. Altered States: “Players treasure the enjoyment from their internal experiences in reaction to the visceral, behaviour, cognitive, and social properties. These players play for internal sensations such as Excitement or Relief from their thoughts and feelings.”
  4. The people Factor: “Players use games as mechanisms for social experiences...these players enjoy the emotions of Amusement...coming from the social experiences of competition, teamwork...”

- Yee [75] using data mining techniques tried to isolate the aspects that mostly motivate players to play on-line games. The isolated factors are:

  – Achievement
  – Social Play
  – Immersion

- Schell in his book [76], proposes interesting game design techniques, providing the reader with countless lenses through which to look at the aspects of the game that is being developed. These

lenses are very useful to identify and focus on a particular feature that manages to engage different categories of players. It is thus possible to highlight how the nature of "*Fun*" in a game can be built by leveraging many aspects that are attractive to players.

- Begy &Consalvo [77], through questionnaires administered to players of the online game Faunasphere, have shown that what generates the greatest attachment to the game is the pleasure (internal motivation) that the players feel in achieving goals.

- According to Koster [78] what makes a game interesting is closely related to the difficulty that the player must face. It defines the concept of "*Fun*" as "the processing of learning and mastering the game" and when the game is mastered, boredom arise.

- Always linked to the concept of difficulty and skill, Csikszentmihalyi [79] proposes the theory of Flow, according to which if the player is subjected to tasks that are adequate for her skills, then the player in performing those activities manages to achieve the state of Flow, a condition of satisfaction and complete absorption where time flies and the player feels pleasure.

All of this research can lead to the assertion that there is not a single characteristic that makes a game "*Fun*", on the contrary, this state can be reached along different paths that always satisfy some of the desires of human nature.

Finally, we present one of the psychological theories that best seems to be able to unify and collect many of the aspects found in the various studies presented so far: Self-determination Theory (SDT).

## 4.3 Self-Determination Theory

This theory [80] was born from the 1970-80s research on motivation by Edward L. Deci and Richard M. Ryan and states that every person is looking for some basic needs. Both internal and external motivation exert important pressures on human behaviour and push us to fill the three basic needs of every human being indicated by the SDT model and summarized well by Lee [81]:

- Autonomy: “Feeling like you know what you are doing”.
- Competence: “Feeling like you have control over your life and that your action matters”.
- Relatedness: “Feeling like you and your actions matter to other people”.

Only recently Rigby [82] has shown that this theory seems to be a very good tool that can be used to discover why the human ability to play is so powerful and what makes videogames so appealing.

An interesting reflection on how video games are an excellent tool to meet these needs is proposed on the TeachThought website: “Over the centuries we’ve gravitated towards experiences that make us feel more competent, more autonomous, and more related because these experiences make us feel good and keep us mentally healthy. These needs can be fulfilled in any number of ways: through work, school, friends, sports, and hobbies. However, sociologists are beginning to understand that video games are one of the most seductive of all of these activities because they fulfil our psychological needs more efficiently than almost any other activity” [83].

## 4.4 Best Practices for a Good Game Design

After presenting the countless studies conducted on the characteristics and aspects that contribute making a game “*Fun*”, we describe the good practices used during the development of games for learning in this project. The aim of applying these principles during the development of games allows the creation of usable (playable) and fun games. It is also interesting to rediscover how these approaches fit in perfectly with the previously discussed Self-Determination Theory.

### 4.4.1 Meaningful Play

In the book Rules of Play [66], Salen & Zimmerman describe meaningful play as the goal of successful game design. To achieve meaningful play, the player must have a sense of control over the game’s outcomes. The game must be able to allow the player to perform certain actions but

must also be able to make the player understand the meaning and value of the actions taken. In short, it is necessary that the player have the perception that the actions taken during the game are significant. In the case of games for learning this aspect acquires a double value: not only must the player's actions must be meaningful in the context of the game, but the actions themselves must also mediate and facilitate the process of acquisition of the didactic concepts that the game is trying to make the player learn. If the player can perceive this double nature of the actions taken, she will also be able to appreciate how the game is helping her improve her knowledge.

### 4.4.2 Clear immediate feedback

At the heart of human interaction with anything else, be it a computer, a human being or an instrument, the aspect of feedback perceived by the execution of an action is fundamental. Without clear feedback, in fact, the person cannot understand the effect that her action has had on the interaction process. To be clear, this feedback must also be quantifiable and immediate. In this way it is possible to rework the result obtained from the interaction and evaluate its effectiveness and, if necessary, modify it. The lack of immediate clear feedback in the field of videogames, risks causing a lack of understanding of the result of the actions carried out by the player. This does not allow her to understand the result of the actions performed and makes the result appear random, thus affecting meaningful play.

### 4.4.3 Simple and direct interaction

This aspect is very important, and it is even more important if the target audience of players is potentially composed of non-gamers. People who have never played video games, in fact, can find it difficult as they are facing many new features all at once. For this reason, it is very important to allow the player to perform actions within the game that are as simple and direct as possible. This facilitation must also be guaranteed by the context of the game, which must push the player to try to make choices that are consistent with the represented world. The SG should be accessible and intriguing for as many users as possible, especially if the goal

is to educate the general public which includes non-gamers who may not be accustomed to game language and interface conventions. Particular care has therefore been taken in the development process of the various games so that all interactions are as simple and natural as possible even for people who do not normally use electronic devices. The simplicity of interaction, always accompanied by a phase of initial tutorials, allowed us to maximize clarity and ease of use, as evidenced by the results collected through the playability/usability tests we performed.

### 4.4.4 Challenge

Being faced with a problem to be solved when you think you have the right skills to do so is one of the most rewarding and empowering experiences. This phenomenon is explained in Self-Determination Theory regarding the concepts of autonomy and competence. If the player of a video game is presented with a challenge with clear goals to achieve, and this task requires skills she has acquired, the player will be able to perform at her best and allow her to achieve a sense of autonomy and competence. At the base of the concept of a challenge is the uncertainty of the result that can be obtained in function of the abilities employed to try to resolve a task. This concept has already been mentioned previously in the section related to psychological theories. The theory that best frames the state of grace that you can achieve in these situations, is certainly the Flow theory presented by Csikszentmihalyi [79]. To maintain the right level of attention and engagement during the game, the player is required to perform increasingly complex tasks to allow him to make use of the knowledge gained during the game experience. This leads the player to try out a sense of mastery and solve increasingly complex situations.

### 4.4.5 Fantasy

The element of fantasy represents the imaginary virtual context where the actions of the game take place. It turns out to be one of the elements that help to create the immersion of the player in the game, the sense of presence, promotes the flow and, if well designed, leads the player to believe that she is in a completely different place than where she really is. Fantasy is recreated in the world of video games in two forms:

- A form of aesthetics, composed of the graphical and acoustical representation that generates the virtual world in which the player plays the game.
- A narrative form used to tell the player important information about the game and the story.

In the field of games for learning, the element of fantasy is an excellent tool to be able to convey information that otherwise, as in the field of genetics, would be too complex to transmit to the user. The possibility of using fantasy environments, such as living within a human cell, provides a great freedom of representation of the concept that you want to teach. In this way, the task of representing complex topics such as genetics is facilitated.

Another important aspect of the game narrative is the humour and informal language with which the texts of the games developed were written, especially in the adventure game. Studies [84] show that the effect of humour and laughter can reduce anxiety, reduce stress, increase self-esteem, improve self-motivation, bolster mental sharpness and promote learning by creating a positive and emotional environment.

### 4.4.6 Curiosity

We can define curiosity as the pleasure of discovering new things. Curiosity is the ingredient that keeps the motivation and attention of the player high. Several elements have been integrated into the developed games to keep the players' curiosity alive in the various phases. New elements have been introduced as content unveiled during the game, exploiting the narrative. This is done to involve the player from a psychological point of view; making her want to know how the story will end.

CHAPTER 5

# Design and Development of Games for Learning related to Genetics

My work is a game,
a very serious game.

Maurits Cornelis Escher

Through this chapter, we introduce the creative process used during the development of games for learning related to genetics. We start by identifying the learning contents, highlighting the basic ideas, we then describe the first developed prototypes along with the testing and development phases organized in close contact with the general public.

Finally, an in-depth analysis of the software and the deployment platforms that would best allow the use and distribution of the games is reported.

## 5.1 Design Techniques User-Oriented

In the 50s and 60s, the development of creative techniques and the introduction of new design methods allowed and encouraged the formalization of an approach to solve problems in a creative way. Archer [85] and several other authors have fostered the evolution of this new field

of research, developing methods to facilitate and regulate the creative process.

This section illustrates the two design techniques:

- **Design Thinking Process**(Figure 5.1)
- **Human Centred Design**(Figure 5.2)

These two techniques deal with partially different design aspects, they are therefore complementary and can be integrated with each other.

The Design thinking Process technique is based on innovation and the search for possible solutions to the problem, keeping the user at the centre of the process, while the objective of Human Centred Design is instead to improve the usability and user experience of a given product or service.

These two approaches, however, are easy to combine; they are based on a similar iterative procedure and both require the involvement of stakeholders at all stages of the development process, from analysis to evaluation. Let's introduce and detail the two different solutions used during the development of the project.

### 5.1.1 Design Thinking Process

The Design Thinking Process is a design methodology used for the creative resolution of complex problems. It allows you to understand user needs from the start and generate tailored solutions.

The key points of this approach are:

- Research and understanding of user needs
- Generating many ideas through brainstorming sessions
- The development of prototypes that are tested by users right from the start

Design Thinking is based on multidisciplinary, collaboration between different teams of experts who combine their different skills to address the problem from different points of view and make solutions and improvements originated through the union of their skills.

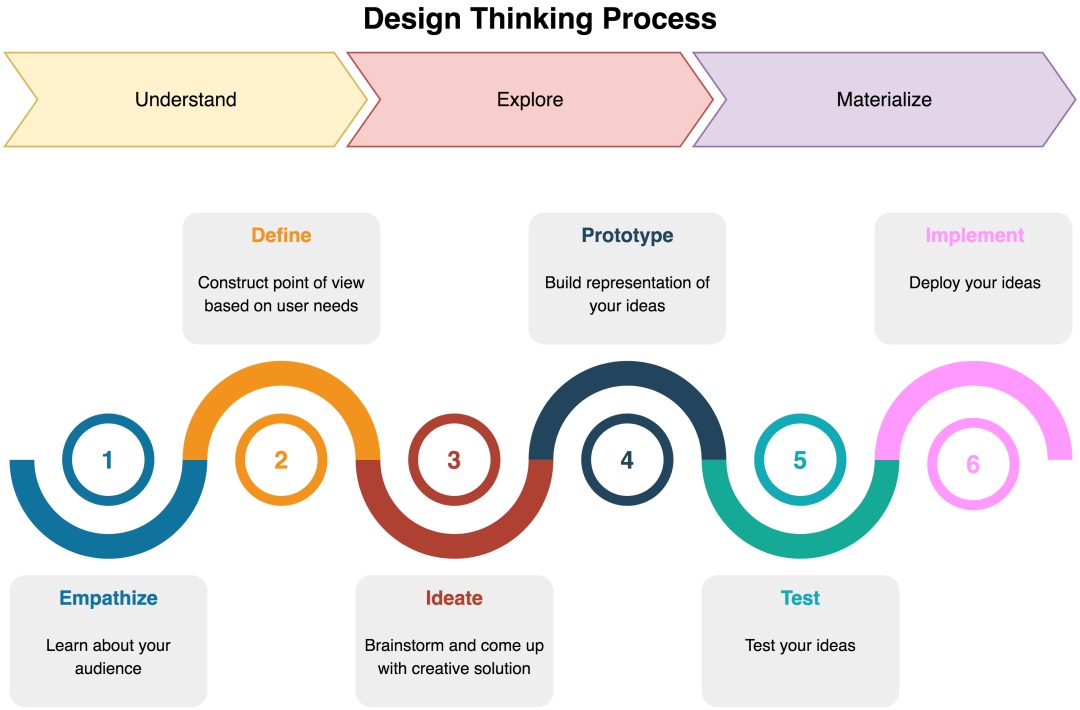


**Figure 5.1:** *The Design Thinking process is an iterative and flexible process able to bring ideas to life based on how real users think and behave.*

### 5.1.2 Human Centred Design

Human-centred design (HCD) is an approach to the development of interactive systems, specifically oriented to the creation of usable systems by the user. This framework allows to develop solutions while maintaining the human perspective in all phases of the problem-solving process and is based on the following steps:

1. Analysis
2. Design
3. Evaluation
4. Implementation

The process has been described by several authors and even by some ISO standards, such as ISO 9241-210:2010 Ergonomics of human-system interaction - Part 210: Human-centred design for interactive systems [86].

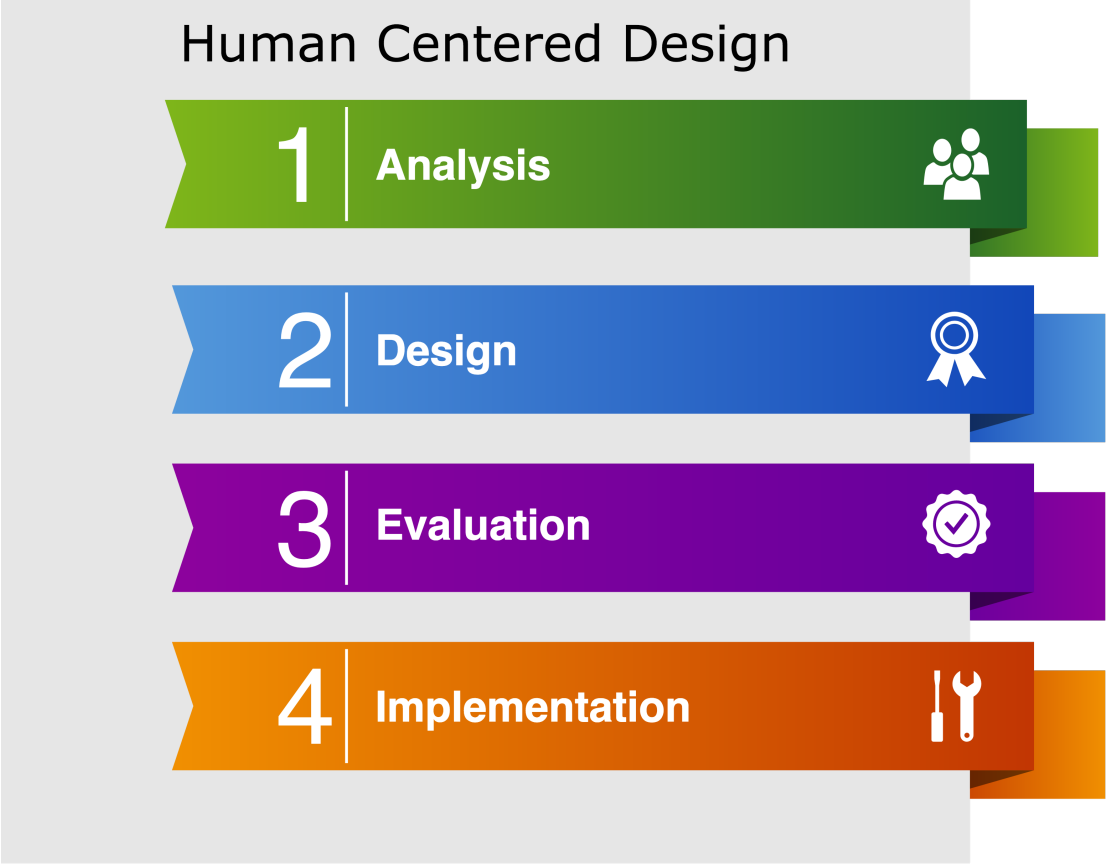


**Figure 5.2:** *The Design Thinking process is an iterative and flexible process able to bring ideas to life based on how real users think and behave.*

In literature, it is possible to find slightly different processes; all of them, however, are guided by a common philosophy: to base the project on the real needs of the user.

Let us summarise the added value of using both techniques. The use of design thinking allows the identification and testing of potential solutions that, through Human Centred Design, lead to the creation and refinement of a user-oriented product.

## 5.2 Interdisciplinary team for content decision

The development of video games is a highly interdisciplinary activity, as it involves mathematics, computer science, physics, art, psychology, anthropology, design...

The serious games described herein were designed by a multidisciplinary team composed of psychologists, computer scientists and a science journalist (with a biological background). They facilitated the identification of the basics of genetic knowledge about which the general population should be educated in order to be able to use and process genetic information.

After a careful analysis of the state of the art, several meetings were organized with the aim of outlining the contents of the SG. The psychologists proposed the most functional ways to convey content through the games to foster the learning process. From these functional specifications, computer scientists developed a first prototype of the game suite that was been later refined and tested.

According to the good game design practices introduced in chapter 4, intriguing and fun mechanics were added to balance the "serious" aspects of the games with elements of pure entertainment.

The level of complexity of genetic content was balanced with the intent of making games comprehensible and usable to most of the people.

### 5.2.1 Games Content and Genetic topics review

The research to determine which aspects of genetics should be taught to enable the understanding of how genetic tests can impact people's lives was carried out in two phases.

The first phase identified trending topics on genetics and the nature of

the target audience. In practice, all the material that would allow us to understand which issues related to genetics were considered interesting and useful to propose to a specific audience, in the form of games, was collected.

In the second phase, a work of synthesis and reflection was carried out to evaluate which themes, according to our multidisciplinary group, were of fundamental importance to sensitize people on issues related to DTC-GT and the consequences that this new technology could have had on their lives.

After a careful analysis we came to the conclusion that it was necessary to introduce some biology content that would allow us to explain, for example, how procreation is related to the transmission of genetic traits to offspring, or how the environment can affect our organism, or how the probabilistic nature of genetics is strictly necessary for the proper understanding of genetic risk. Right from the start, however, we noticed the limitations of a single biological approach to the problem, as this lacked the whole emotional dimension, which is fundamental in the decision-making process for people who decide to undergo a genetic test.

To fill this gap, we chose to introduce, through a strictly didactic part, the understanding of the fundamental concepts of genetics, which are then applied in a real-life simulation, in which the player must use what she has learned to make the protagonist of the adventure live in the best possible way.

Our analysis determined that it was necessary to use simple casual games to convey concepts that are relatively distant from each other but fundamental for the understanding of this broad theme. The simple approach taken was to develop the scientific content considered fundamental within different mini-games.

## 5.3 Genetics contents chosen for the Mini-Games

The basic genetics topics on which the 4 mini-games were designed are:

- Heredity: the process that allows genetic traits to be transferred from one generation to the next.
- Mutation: The variation of our DNA bases can be random or depend on external factors called mutagens.

- Gene interaction: The interaction between different genes, usually genetic pathologies are due to the interaction of multiple genes and not from a single gene.
- Genetic Susceptibility: The detection of genetic variants strongly associated with a disease; it represents the probability that a person due to some mutations in her DNA and the interaction with the environment, manifests that disease during her life.

Below is a brief description of the first two fundamental concepts dealt with by the mini-games developed for this project, that cover precisely the issues of heredity and mutation. The idea is to provide a quick review to those readers who do not have a solid genetic basis, to better understand the issues covered in the games and how the part of knowledge has been included in the developed game mechanics.

### 5.3.1 Heredity

Every living being is made up of cells. In eukaryotes, each cell has within its nucleus a variable number of chromosomes representing its genome or genetic heritage: the DNA. The DNA (deoxyribonucleic acid) of a cell is a long sequence of amino acids. Genes correspond to portions of the genome located in precise positions within the DNA sequence, which contains the information necessary for the synthesis of proteins, fundamental for the development and proper functioning of most living organisms. Every living being is therefore characterized by a specific genotype that is the set of its genes.

The expression of this genotype, influenced by the environment in which the living being develops, is manifested through the phenotype, which is the set of morphological and functional characteristics of an organism. Each gene is present in (at least) two copies, called alleles, of which one inherited from the mother and one from the father. If two alleles are equal then the individual is called homozygous, while if they are different then they are called heterozygous.

An allele is also called dominant if it has an effect, that is, it manifests itself in the phenotype even if there is only one copy (heterozygous individual). It is called recessive if it manifests itself in the phenotype only in the presence of two copies (homozygous individual). Heredity describes

how genetic traits are transferred from parents to children through successive generations.

Autosomal dominant inheritance is a type of inheritance introduced by Gregor Mendel that describes how, in carriers of dominant alleles, this causes the development of a phenotypic characteristic, which can also be a disease. In this type of heredity, the characteristic manifests itself in whatever subject possesses the dominant allele without distinction of sex (complete dominance) and both in the dominant homozygous and in the heterozygous, but not in the recessive homozygous, where, in the absence of the dominant allele the characteristic does not manifest itself. Called A, the dominant allele that causes the characteristic of the phenotype, all AA subjects (dominant homozygous) will have a 100% chance to transmit the character to their offspring and have affected children regardless of the genotype of the partner, a heterozygous Aa has instead a 50% chance to transmit the dominant allele. While the recessive homozygous aa has no possibility of transmission.

Autosomal recessive inheritance, on the other hand, is a type of Mendelian inheritance in which only recessive homozygous type aa are affected by the disease or express the phenotype, while heterozygous type Aa and dominant homozygous type AA are not. In the case in which two subjects of phenotypes aa and Aa are coupled, the offspring will have a 50% chance to show the characteristic with a homozygous aa genotype and a 50% chance not to manifest it.

Below are the key points integrated into the developed game:

1. What DNA is.
2. What genes and alleles are.
3. What the genotype and phenotype are.
4. When an individual is heterozygous and when homozygous.
5. When an allele is dominant and when it is recessive.
6. What Mendelian heredity is.
7. The odds of transmitting a characteristic.

### 5.3.2 Mutation

The DNA contained in the nucleus of each cell of an individual is comparable to the database of its genetic information. At each cell division, the genetic database is faithfully copied to be transmitted from the mother cell to the daughter cells. In the operation, which concerns 3 billion DNA bases, errors are made, which can be more or less serious depending on where they occur. In our organism, there are systems capable of correcting the majority of DNA copying errors. Changes that remain permanently in the DNA are called mutations. DNA mutations can also occur by chance or be favoured by certain external agents (so-called mutagens, physical agents such as X-rays and ultraviolet or chemical radiation).

Over the years, incorrect errors tend to accumulate: the individual ages and her body functions less efficiently.

If a mutation occurs in the cells of the germ line (the egg cell or spermatozoon) of a parent, the child inherits from birth that mutation which, if harmful, predisposes him to the development of a disease.

It should be borne in mind that mutations also have a positive role, since they allow the introduction of a variability between individuals of the same population (the so-called polymorphism), which is one of the levers through which the evolutionary thrust acts, promoting the survival of individuals best suited to certain environmental conditions.

The key points that were integrated into the mini-game developed on mutation are summarised below:

1. To introduce mutation as an "inevitable" phenomenon from DNA duplication.
2. The existence of spontaneous mutations induced by mutagenic factors.
3. Evolution keeps the number of mutations under control through correction mechanisms.
4. There are more or less serious mutations.
5. Mutations accumulate with years (ageing).
6. If mutations are in somatic cells, they remain confined to the individual, if in germ cells they are transmitted to the children.

7. Mutations could sometimes be positive, because they make it possible to adapt to the environment.

## 5.4 Initial prototypes of the games

During the first experimentation phases of the project, prototypes of simulations and mini-games were developed. In this way, it was possible to start collecting information and reasoning about the reactions observed during general public gaming sessions, regarding the aspects of the game mechanics and the experiences perceived during the game phases.

Before describing the final versions of the three SG (chapter 6), obtained after various refinements and iterations, let's briefly introduce the concept of all the mini-games designed and prototyped in the early stages of the project. Some of these prototypes will be developed and completed by the end of the Mind the Risk project.

### 5.4.1 Simulation of heredity

The first prototype of a god-like game was focused on the theme of heredity, that is, how genetic traits are transmitted from one generation to the next, following the rules of Mendel.

The player is presented with a 3D mini-world (Figure 5.3) on which two different populations live. The two populations are identified by two distinct colours: blue, which represents the dominant characteristic and red, which represents the recessive characteristic.

The populations are initially separated by a wall like the Chinese wall, which prevents the two populations from coming into contact and then to mix the different genetic characteristics that give rise to the colour of the inhabitants.

During the simulation, the player acts as a god and can modify the environment. She can destroy the wall allowing the union of the two populations and then observe how the passing of generations varies the colour of the inhabitants.

For this prototype, a system for the simulation of the inhabitant's life has been developed. At the beginning of each simulation, a different number of female and male inhabitants for each population is dynamically instantiated, this initial configuration will then lead to different

results of the simulation.

For example, if the blue population is instantiated only with males and the red ones only with females, surely already from the first generation we will have inhabitants with both alleles, dominant and recessive, the blue inherited from the father and the red from the mother but all the new-borns will present the blue phenotype because it is a dominant trait.

Each inhabitant also has a biological age that increases with the advancement of the simulation. Each inhabitant can reproduce with other inhabitants within a certain age range, in this way in the simulation children and elderly people cannot proliferate. At the beginning of each simulation maximum age of each inhabitant is established drawing on a parameter that sets the average age of the male and female population. At that age the inhabitant dies, thus varying the number of total inhabitants and modifying the statistics of the genotypes shown to the player during the simulation.

The possibility of varying all these parameters allows for the creation of a multitude of scenarios and then illustrate the different aspects related to the Mendelian inheritance, thus allowing the player to acquire the notions necessary to understand the phenomenon.

### 5.4.2 Simulation of Susceptibility:

This prototype was developed to explain the concept of genetic susceptibility to a disease, also called genetic predisposition; that is the probability that a person due to some mutations in her DNA combined with environment interaction, manifests that disease during her life.

To explain the probabilistic nature of the phenomenon, we chose to develop an application that could act on 100 people, in order to easily explain the concept of percentage and how a disease with a susceptibility of 30% occurs in 30 people out of the total of 100, who represent a sample of the population.

It was therefore decided to develop a 2D simulation of a micro-world (Figure 5.4), which allows the player to assign the percentage of susceptibility of the entire population to a given disease. The player, guided through a tutorial, has the ability to simulate the passing of time to verify how the disease will manifest itself on part of the population.

Subjects who manifest the disease change their colour from green

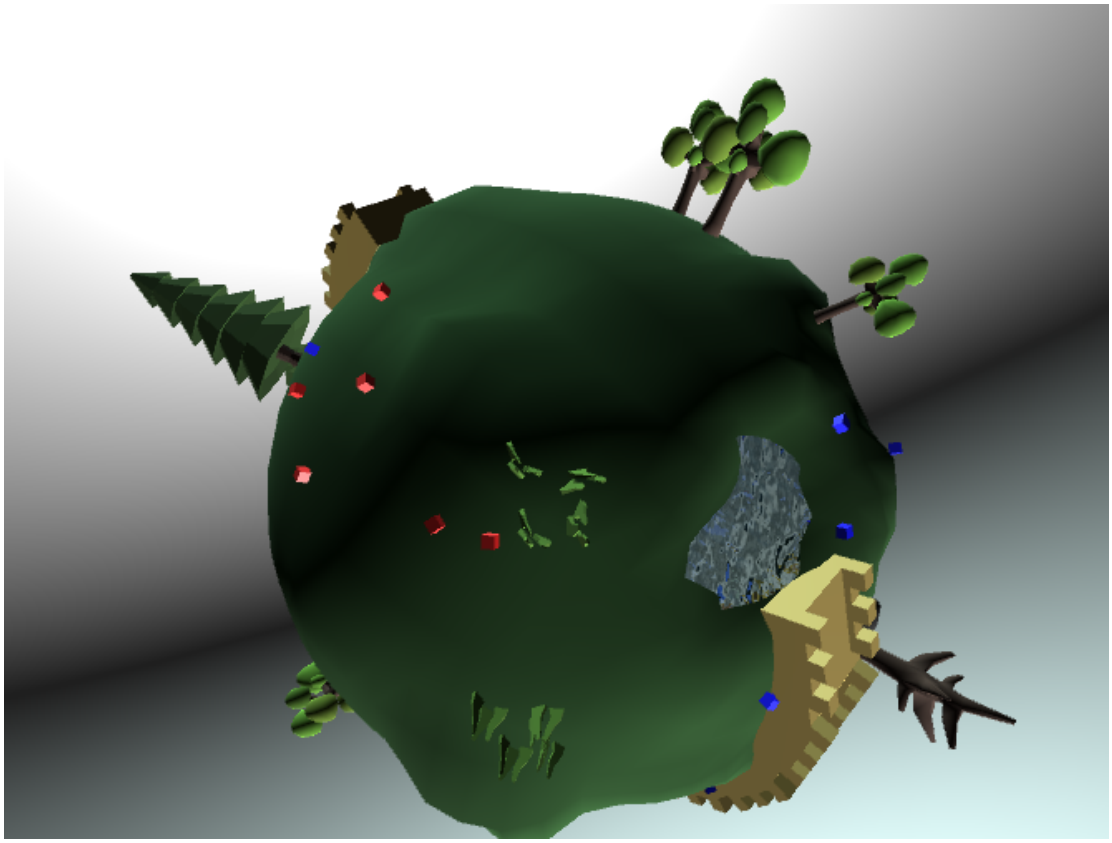

**Figure 5.3:** *This is the first prototype developed to focus on heredity. The player is presented with a 3D mini-world on which two different populations, identified by two colours, live. The blue population, which represents the dominant characteristic and red, which represents the recessive characteristic. It is possible to tune some population parameters to create a multitude of scenarios thereby illustrating all the different aspects of Mendelian inheritance.*

healthy people, to orange sick people and then end up with the red colour that represents the onset of death.

After testing the prototype on several people and discussing the advantages and disadvantages of this solution within the multidisciplinary team, the idea was abandoned in favour of other solutions described below for the following reasons:

- The idea of showing the state of death of the inhabitants of the planet was bad, as it could hurt patients' sensibilities.
- The lack of game mechanics made simulation boring and unattractive.


**Figure 5.4:** *The first prototype of a micro-world, developed to illustrate the probabilistic nature of the genetic susceptibility to a disease. The player has the ability to simulate the passing of time to verify how the disease will manifest itself on part of the population. Subjects who manifest the disease change their colour from green, healthy people, to orange, sick people and then end up with the red colour that represents the onset of death.*

### 5.4.3 From simulation to game: Susceptibility V 2.0: Sushi-eptibility

In the second version of the game, we decided to abandon the simulation route to leave room for a more fun mechanic that exploits "risk" to explain the concept of probability on which the susceptibility is based. The player in this version no longer acts on an entire population to understand the probabilistic nature of the phenomenon, but on the choice of pieces of sushi (Figure 5.5) within a restaurant.

The game takes place in two distinct phases. In the first phase, the player sees pieces of sushi flowing on a treadmill that may or may not be rotten and must select a total of ten pieces.

In the second phase of the game, however, the player is asked to choose which of the 10 pieces caught he would eat. This event represents the manifestation or not of the pathology during a whole life. If the player draws a piece of good sushi, she can continue with the next level, otherwise, the game ends, recalling the concept of the onset of disease.

The difficulty of the game is incremental. The level of susceptibility, represented by the percentage of rotten pieces on the treadmill, is increased and it will, therefore, be more likely for the player to select inedible pieces.

Here again, after the multidisciplinary group analysed the prototype implementation we decided to modify part of the game. The concept of susceptibility also had to be linked to the context of interaction between the genotype and the environment and not to mere probability. It was therefore decided to implement this aspect in a new version.

### 5.4.4 Susceptibility V.3: Ambient, ageing and mutation:

This simple game was developed to integrate the different aspects related to the probabilistic nature of the onset of diseases due to mutations and interactions between the environment and our genetic make-up.

The protagonist of the game is a man who advances between different scenarios while walking and ageing (Figure 5.6). The protagonist needs to continue to feed himself to survive and be able to continue in the game. To do so, he must choose whether to enter or not in the various sushi restaurant on his path. Inside the restaurant, the player will have to randomly fish a single piece of sushi. Some pieces of sushi while appear-

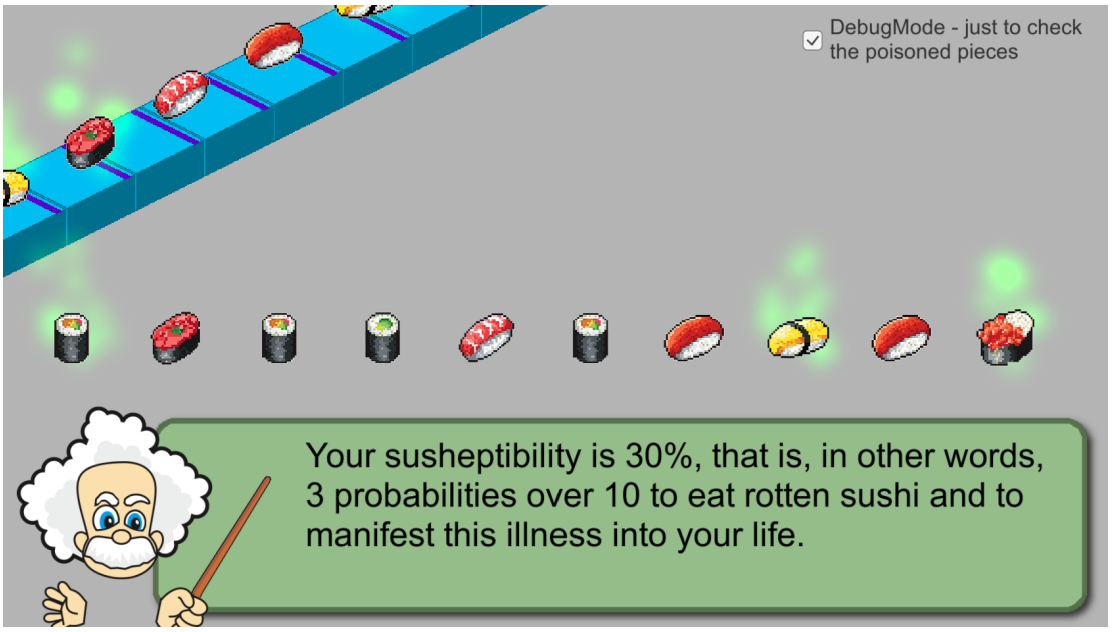


**Figure 5.5:** *The player must select ten pieces of sushi that may or may not be rotten. The player is then asked to choose which of the 10 pieces caught to eat. If the player draws a piece of good sushi he can continue to the next level, otherwise, the game ends, underlining the probabilistic concept of the onset of disease.*

ing edible are poisoned. The choice that the player must make, whether or not to enter a restaurant is influenced by the level of hunger of the avatar, if the level of hunger is low, the player can for example decide to avoid the sushi-bars that are found in polluted environments, where the presence of contaminated sushi is higher than in places where there is no environmental pollution. The number of poisoned sushi also increases with the advancing age of the player, this aspect was introduced to explain the link between biological age and mutations that occur within our DNA.

### 5.4.5 Simulation of a healthy lifestyle

To explain the concept of a healthy lifestyle, it was decided to reuse the concept of the god-like game introduced earlier. The player, in the role of a god, must make the people who live in the world created by her survive as long as possible (Figure 5.7). To do this, she can decide what kind of food to use to feed the population. Different types of food are available: healthy and less healthy.

For example, healthy food is made up of white meat (such as chicken

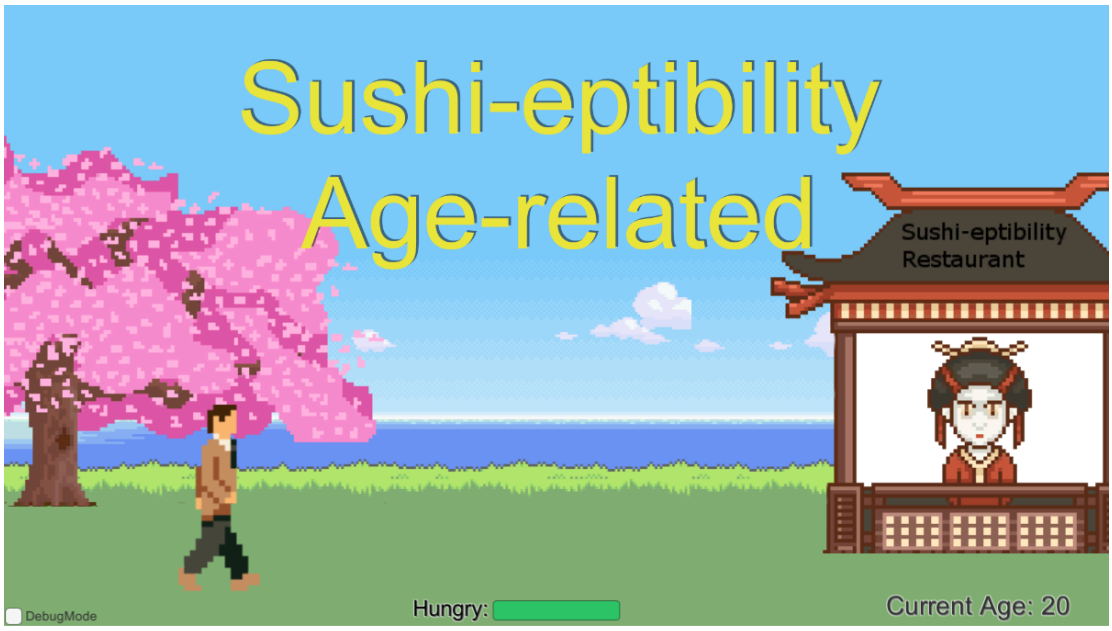


**Figure 5.6:** *The player needs to feed herself to survive and be able to continue in the game. To do this she must choose whether to enter or not in the various sushi restaurant present on her path. Inside the restaurant, the player will have to randomly fish a single piece of sushi. Some pieces of sushi while appearing edible are poisoned and cause a game over when eaten. Sushi bars near polluted environments have a higher number of contaminated sushi pieces.*

and fish), fruit and vegetables. The less healthy food is represented by sweets, red meat and animal fats. Each type of food once consumed changes the state of health and mood of the population. The player will then have to skilfully choose which types of food to provide to the population during the game. The choice of the various foods is based on the Mediterranean diet, evaluated in various studies as the most balanced and optimal for health [87]- [88]- [89].


**Figure 5.7:** *The player, in the role of a god, must make the people who live in the world created by her survive as long as possible. To do this she can decide what kind of food to use to feed the population.*

### 5.4.6 Gene Interaction - first prototype

This prototype was developed to deal with the topic of interaction between genes. This phenomenon occurs when specific alleles and/or products of two or more genes influence each other, these interactions in some cases can lead to changes in the phenotype of the individual.

To explain this concept, we decided to implement the use of metaphors within a puzzle game. Each gene within the game takes the form of a bridge (Figure 5.8). In each level, the player must be able to bring several cars safely to a destination. The roads are interrupted by several bridges. The player must decide which bridges/genes to activate. Activating a gene, the bridge will close allowing the passage of the car.

This activation, however, will change the state of the other bridges, thus recalling the concept of interaction between different genes. The player, through the game, learns to understand the rules of interaction of the different genes and must try to minimize the number of moves necessary to bring all the cars to the arrival. If the sequence of activation of the genes is wrong not all the cars will be able to complete the level. The occurrence of this situation is compared to a harmful interaction between several genes, which causes problems in the body.

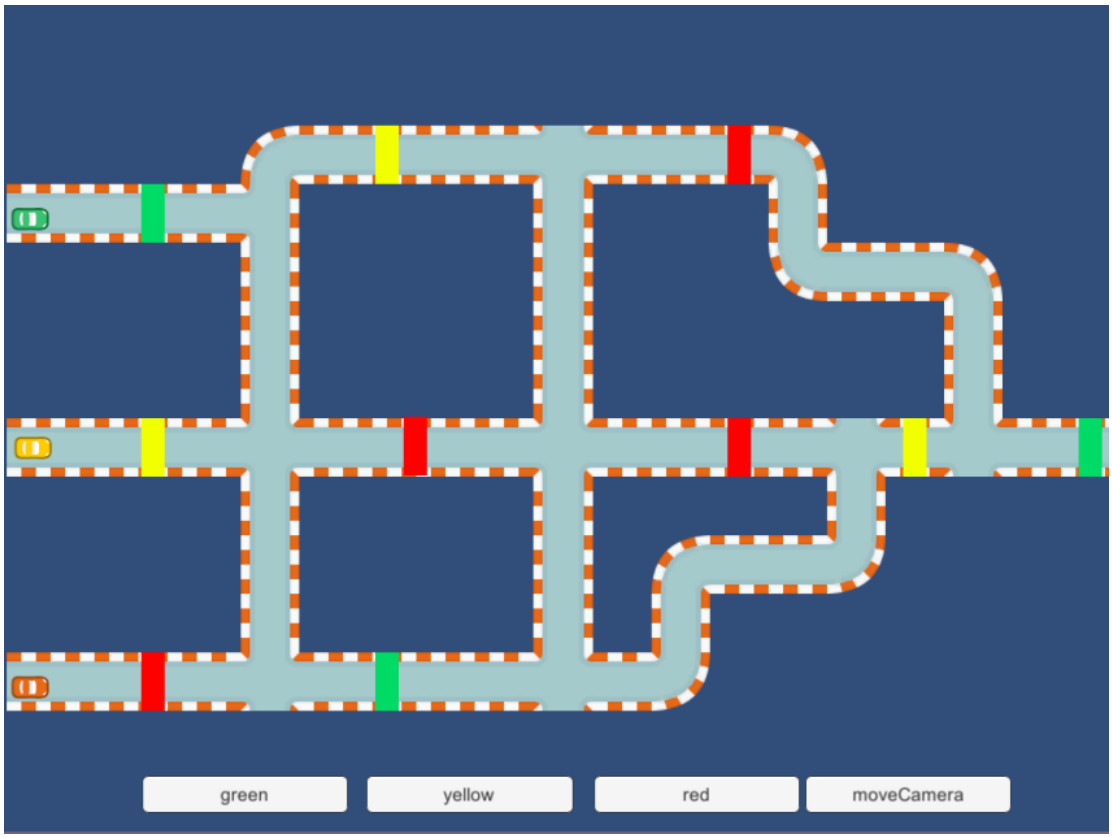


**Figure 5.8:** *We decided to implement the use of metaphors within a puzzle game to explain the concept of gene interactions. Each gene in the game is represented by a bridge. In each level, the player must be able to bring several cars safely to a destination by activating the right sequence of bridges. This activation, however, will change the state of the other bridges, thus recalling the concept of interaction between different genes. The player, through the game, learns to understand the rules of interaction of different genes and must try to minimize the number of moves necessary to bring all the cars to the arrival.*

### 5.4.7 PACMAN Gene Interaction - second prototype

From a preliminary analysis, the first prototype was too far from the topic and not clearly understandable by the target audience. So, we decided to try and generate game mechanics that would allow the general public to better understand how the interaction of multiple genes could affect some of the characteristics of the phenotype.

It was therefore decided to use an arcade game, similar to Pacman. In the original version of the game, the protagonist must whiz through a maze, eat all the white dots scattered around and avoid being caught by the ghosts that wander around the level. There are special dots that give the player the ability to devour even the ghosts for a limited time. Another game mechanic is the ability to eat fruits that appear during the game which provide extra points.

In our revised version of the Pacman (Figure 5.9), most of the game mechanics are similar to the original. The only difference introduced is the generation of fruit bonuses. In our game, the fruit does not appear randomly within the level but is generated by the interaction of genes that appear as spaceships outside the framework of the game. When two or more genes collide they give rise to a particular fruit that falls in the game area and can be consumed by the player. The fruit generated from time to time will give special powers to the Pacman, sometimes positive: super speed, invincibility, ability to cross the walls, while other times negative: slowing down, inability to eat, reversal of control commands. By implementing these dynamics, we explain to the player how the interaction of some genes can go to modify the phenotype of a living being sometimes in a positive way sometimes in a negative way.

## 5.5 Choose the right genre for a wide audience

Because Mind the Risk project is mainly aimed at the general public, a considerable effort has been made to produce original research on the issues of the project, and then summarize them by simplifying the results obtained to disseminate the findings. This way it is possible to make them available to the general public.

Maintaining the same principle during the games analysis phase, several focus groups were carried out with the aim of understanding which

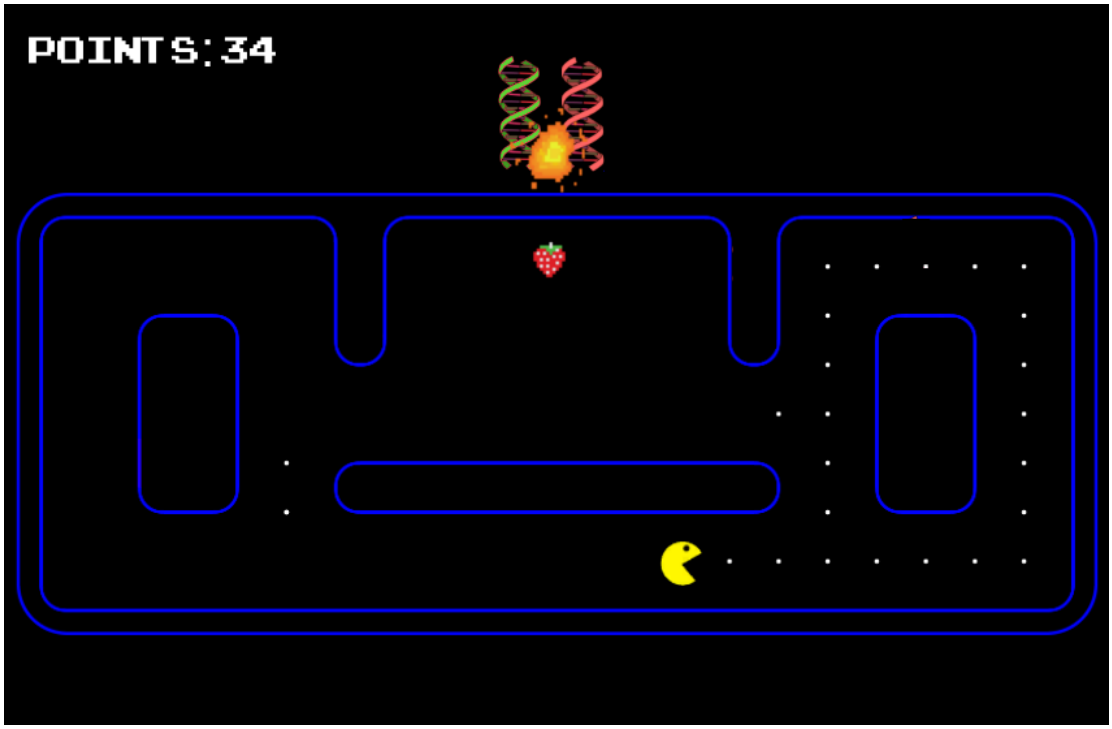


**Figure 5.9:** *In our revised version of the Pacman, the only difference from the original is how the fruit bonuses are generated and how they influence Pacman's behaviour. When two or more genes collide they give rise to a particular fruit that falls in the game area and can be consumed by the player. The fruit generated from time to time will give special powers to the Pacman, sometimes positive while other times negative. By implementing these dynamics, we explain to the player how the interaction of some genes can modify the phenotype of a living being.*

games genre and which game mechanics could work best for the general public and how to correct the shooting for the development of the final versions of the games.

It was noted that it was necessary to reduce the themes present in every single game, in order to make the learning process more linear and simpler. The target audience of the games identified was heterogeneous. For this reason, we have chosen genres of games that are easy for everyone to play, with simple and immediate mechanics. Below we describe the three types of game genres developed, the results of which were appreciated by all players who participated in the experiment of playability.

### 5.5.1 Runner Game

Runner games are games in which the avatar of the player proceeds autonomously through the world of the game which is usually generated procedurally and that can also be theoretically endless. The game controls are usually limited to jumping, attacking or performing a special action.

Typically, the purpose of these games is to get as far as possible into the game world, an operation made increasingly difficult by the complication of the difficulty level as it proceeds.

This type of game has become very popular on mobile platforms, given their ease of use and their relative simplicity from the point of view of computing resources used. Jetpack Joyride and Flappy Bird are perfect examples.

### 5.5.2 Arcade

An arcade game is a videogame played in a special public place with coins or tokens, physically constituted by a machine placed inside a cabinet. These are also called with the term coin-op, an abbreviation of coin-operated, although the term can also refer to games that are not necessarily video, such as pinball machines.

Historically, arcades represented the first generation of video games and the first contact of the public with this new form of entertainment. Between the seventies and eighties, hugely successful arcades such as Space Invaders, Defender, Asteroids, Tetris and Pacman were distributed

around the world.

### 5.5.3 Adventure Game

Graphic adventures are video games based on an intuitive graphical user interface. The game scenes are presented as animated and interactive images and are controlled by pointing devices, commonly the mouse. The use of text, written or spoken, is usually limited to dialogues between characters. The player typically must explore the game world, collect items, clues, solve problems and proceed with the adventure by combining the collected information.

Compared to many other game genres, the focus on adventure stories allows them to make massive use of other narrative-based forms of art, such as literature and cinema. Adventures include a wide variety of literary genres, including fantasy, science fiction, horror and comedy.

Famous examples of adventures include Zork, King's Quest, Monkey Island, The Day of the Tentacle and Myst.

## 5.6 Software used

The Unity 3D game engine [90] was used for its flexibility to develop both 2D and 3D games. Allowing developers to fast prototype and easily deploy multi-platform games (Win, MacOs, Linux, several mobile platforms and consoles).

This feature was particularly useful for this project since games need to be made available for both desktops and mobile.

3D models were built and animated in Blender 3D [91], the state-of-the-art in open-source modelling software, Gimp [92] was used for 2D raster graphic and Audacity [93] was used for the audio editing job.

## 5.7 Platform and Use case

Several focus groups were carried out to find the best way to convey this information and make it available to the greatest number of people. For this reason, the games were developed through the graphics engine Unity 3D [90] that allowed the development and publication of content for both

the Web and mobile devices, which nowadays are the most pervasive channels to reach people.

In the first place, the games were made available through the website of Mind the Risk project, but have already been developed in such a way that they can be deployed also on mobile devices and then made available to the general public through the most popular stores, such as Google play stores for Android and Apple store for iOS.

These were assessed as the most easily accessible channels to the general population through adequate publicity. There is also nothing to stop making the games available to a more demanding audience through channels such as STEAM, which is beginning to have lists of games dedicated to learning and no longer just to entertain.

Several use cases have been designated for the games developed:

- Use of the games by the general public as if they were casual games, to be played during the dead times of the day, on public transport in the commute homework, the evening before falling asleep.
- A more structured use by teachers to deal with this topic in classrooms. This would sensitize children from an early age to these issues in order to form an idea and deepen it over time, having the necessary basis to understand more complex concepts.
- Playing games with patients who must decide or have chosen to undergo genetic testing. This approach allows patients to reflect on different aspects related to the issue of genetic testing, experiment and understand in an intuitive way themes that be more immersive than the reading of a document.

All the developed games are currently made available in Italian and English languages. They were developed mainly for mobile and web platforms and will be available to the public during the last year of Mind The Risk project (2019) on the official website of the project [33];

## 5.8 Questionnaire System developed to test knowledge transfer

To test the knowledge transferred through the games and the self-efficacy perceived by the player before and after the game session, a question-

naire, fully integrated with the game environment, was implemented.

In the developed games we provide through an avatar (virtual narrator) explanations regarding the contents of the games and the actions to be taken by the player. To optimize development time, that in these experiments is the most precious resource, it was decided to reuse the dialogues system already developed to manage the dialogues of the games implemented.

Through this tool, it is possible to provide the participants with the most graphically consistent experience possible and also to automate data collection for subsequent statistical analysis.

With this tool, the virtual narrator can ask the player several questions in the game, and the player can answer them through the User Interface (UI). In this project, 3 types of questions were chosen to test the games knowledge transfer:

- Multiple-choice questions
- Open questions
- Questions with Visual analogue scale (VAS)

## 5.9 System for logging players' choices

In many cases, it is very useful to include in a software the possibility to keep track of the actions taken by the user, to perform subsequent analysis of possible errors or to collect detailed information on users' actions. In such a case it is mandatory to obtain the user's consent to collect these data and, of course, to guarantee the anonymity of the collected data.

In order to be able to deeply analyse the decisions made by the players and measure the learning outcomes earned during the games by a method other than the knowledge transfer questionnaires (chapter 7), it was decided to implement a logging system able to keep track of all the players choices and performances during the course of the games.

This feature will allow a future more detailed analysis of the choices taken by players during the course of the games, related to the health decision making process.

CHAPTER 6

# Games developed and tested: description of the final version

> Life is more fun if you play games.
>
> Roald Dahl

Three different Serious Games were fully designed, developed and tested for this PhD project.

Two mini-games with the aim of introducing different basic concepts of inheritance and mutations (HerediRabbit and MutanTetris) and an adventure game aimed at experiencing the consequences of certain behaviour in situations of genetic risk.

For the development of the mini-games we tried two different approaches:

1. create an ad-hoc game that translates genetic concepts into the game mechanics;
2. modify an arcade game, adding mechanics suitable to convey the genetic concepts.

The first one was to create an ad hoc serious game translating genetic concepts into the game mechanics, therefore we implemented a 2D

jump-and-run game to convey Mendel's laws in an enjoyable way. The second approach was a learning version of an existing game, the arcade Tetris game, which was modified by adding suitable mechanics that depicted concepts related to genetic mutation. Due to the popularity of this arcade game, it could be considered familiar and appealing for most users [94]- [95]. For the adventure game the tipical narrative approach of this genre, based on a dramatic curve, was employed; it has been shown that attachment to the narrative can both increase pleasure and provide background and motivation for the player to become involved in the game [96].

The mini-games were designed exclusively to transmit basic genetic principles and try to improve general public literacy, without referring to genetic risk. They are based on a simplified representation of mutation and Mendel's laws. Indeed, in the serious game named Mutan-Tetris, the game field represents what could happen in a cell's life, with eventual consequences on the organism. In the serious game named Heredi-Rabbit, the game challenges are established on a possible allelic combination that could take place following hereditary transmission.

The adventure game, sought to make players aware of the concept of genetic risk. The player can experience what managing genetic risk means by identifying with an avatar, and acting on his behaviour by taking into account his genetic predisposition. In this kind of game, the player is immersed in a world that includes feelings and emotions in the context of social interaction. The player can interact with other characters in the virtual environment and use the knowledge and skills acquired, in the different situations that arise during the game.

All the games are complemented with a virtual character that acts as a facilitator (see Figure 6.5). This character accompanies players through the different games and supports learning efforts by preserving playability.

## 6.1 Heredi-Rabbit

As mentioned before, the aim of this game is to transfer concepts about heredity (the process through which genetic traits are passed from parents to their offspring), with dominant and recessive genetic variants

(phenotype expression if the gene variant is present in at least one copy vs. gene variant expression if present in both chromosomes)(Mendel's laws).

To help people with no prior knowledge in the field of genetics, a gentle introduction tutorial can be chosen before playing the Heredi-Rabbit game. In this tutorial, several basic notions regarding cells, chromosomes, genes, phenotype and dominant and recessive rules are explained by the virtual narrator using text and simple animated illustrations. A simple introduction to the fundamental aspects of genetic (Figure 6.1- a) and the possibility to practice with Mendel's laws (Figure 6.1- b) introduce the player to the core of the game.

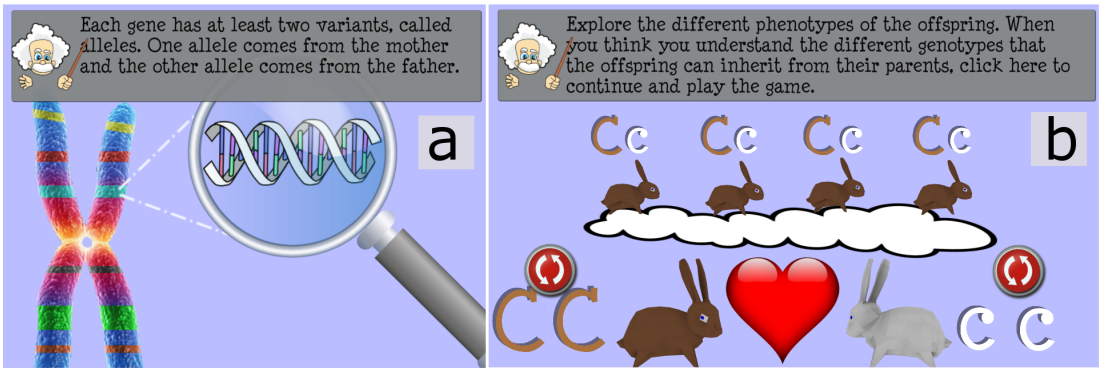


**Figure 6.1:** *a - The player is introduced to the game with an overview of genetic concepts (gene, alleles, genotype, phenotype); b - It is possible to test how Mendel's law works.*

In this 2D jump-and-run game the player must make a rabbit couple with other rabbits in order to obtain an offspring that has a required genetic makeup (final goal of the game session). Every rabbit has its own genotype that causes the colour of its fur (phenotype). The rabbit hops around to grabs carrots, to get energy and to avoids traps (Figure 6.3 - a). When the rabbit has gained enough power it is ready to couple with other rabbits in order to produce offspring.

The final goal of the game is to match the specific genetic make-up presented to the player. The genotype of the controlled rabbit is clearly visible on the rabbit, while the genotype of the other incoming rabbits is hidden. The player should make the decision to couple or not with other rabbits exclusively on their phenotype (Figure 6.3 - b).

The amount of time the player must choose if to couple or not is

limited (imposed-pace), In this way it is possible to keep the level of fun, engagement and attention high, since the player has to remember and apply very quickly what learned previously. When two rabbits mate the game is paused and a romantic view of the new offspring (Figure 6.3 - b), that could be generated by the two rabbits, is shown. All the possible phenotypes of the offspring, generated by the allelic combinations of the parents, are finally shown and the player has the time (self-paced) to evaluate the obtained result (Mendel's law). After a while, the game starts again, and the new rabbit is randomly selected from the offspring.

The new-born, that inherits the genetic make-up following Mendel's laws, becomes the new runner rabbit (Figure 6.3 - c). The difficulty of the game can be tuned changing the running speed of the rabbits, to give more or less time to the player to think if the incoming rabbit is appropriate to reach the goal and mate with it. The game ends when the newborn running rabbit achieves the genotype goal given at the beginning of every match.

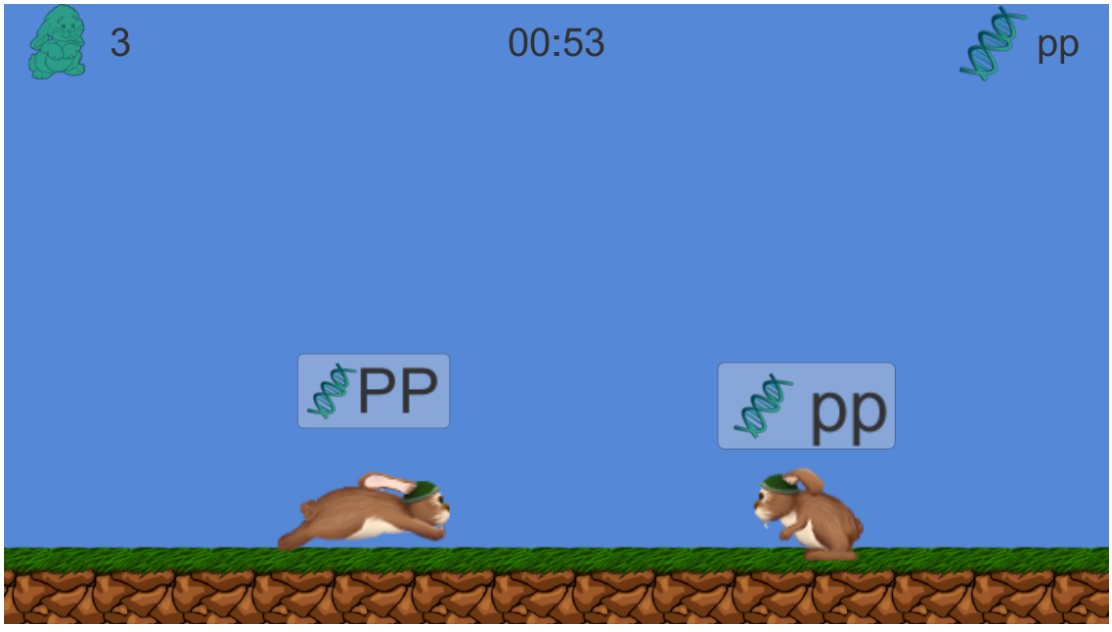


**Figure 6.2:** *Screenshot of the initial prototype version of the game.*

## 6.2 MutanTetris

The goal of this game is to explain different aspects of mutations:

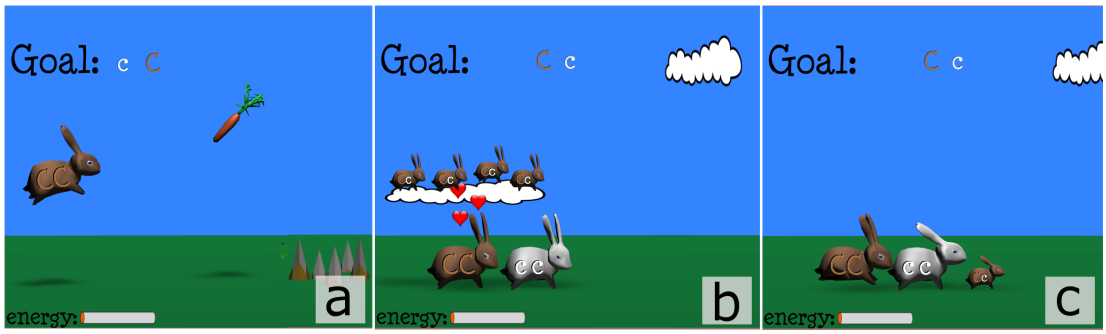


**Figure 6.3:** *a - The player controls the rabbit that should grab carrots to get energy and avoid traps; b- The player can choose to have the running rabbit mate with other incoming rabbits based just on their phenotypes and have an offspring; c- The newborn rabbit inherits the genetic make-up following the Mendel's laws. If the target genetic make-up is achieved (goal) the game ends.*

- what a mutation is (an alteration of the nucleotide sequence in the DNA);
- which elements contribute to it (errors, mutagens or environmental causes)
- that some mutations can be fixed or not
- that some mutations are hereditary
- that mutation rate increases with age.

A simple introduction to the fundamental aspects of cell duplication (Figure 6.4 - a) and duplication errors (Figure 6.4 - b) are explained by the virtual narrator using text and simple animated and interactive illustrations.

In the tutorial, the player learns that some mutations are fundamental because they provide genetic variability, the basis for evolutionary changes over time. However, the game focuses on harmful mutations, both somatic (which involve any cell of the organism except reproductive cells, and are not usually transmitted to descendants), and germline (which can be passed on to the offspring through reproductive cells), that may adversely affect the function of a cell (mutations occurring in the coding DNA portions). To introduce these themes, we used a very famous arcade game, Tetris, modifying its mechanics by adding bricks with new shapes (Figure 6.5).

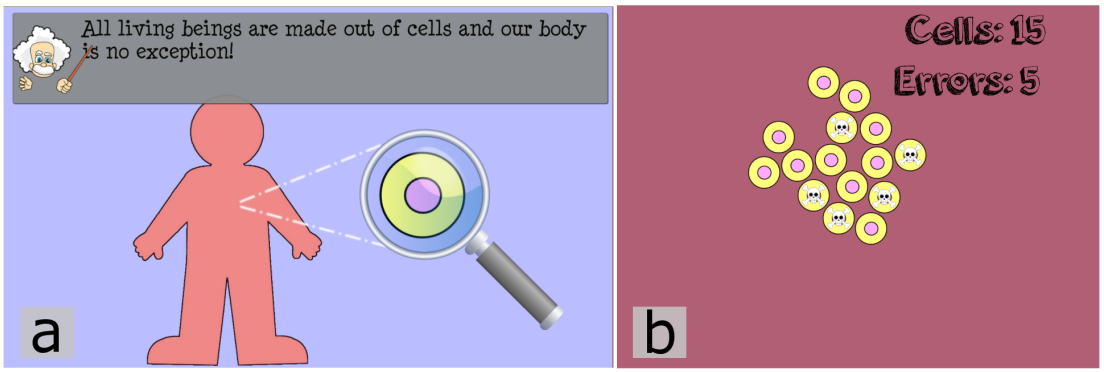


**Figure 6.4:** *The virtual narrator gives to the player an introduction about the fundamentals aspects of cell duplication(a) and duplication errors using simple animated illustrations. An interactive part is also presented to the player (b), that must duplicate a predefined amount of cells avoiding duplicating cells containing errors.*

In the classical Tetris version, seven differently shaped bricks exist, each with its own shape and colour. Bricks fall from the top of the scene and the player has to rotate and shift them, while falling, in the best way to form full lines at the bottom, avoiding to leave empty spaces. To maintain fun and engagement, the amount of time to find the best position and orientation of each brick is limited (imposed pace). Every time a line is filled up it is erased, and the player gains points and the blocks in all other rows are shift downwards by one row. In our revisited version the playing field metaphorically represents the cell environment, the blocks represent the genetic material and the elimination of a row represents the correct encoding of the DNA. Everyone who has ever played Tetris knows very well the shape of the seven bricks. Levering on this aspect we have introduced three new bricks with different shapes, enriched with blinking eyes and dark colours that represent mutation. The intended effect is to make the player feel that something unexpected and unusual may happen. When such bricks appear, the game is paused (self-paced) and the narrator explains in detail the origin of the "mutation". When the player is confident with it, the game is resumed. Two of these new bricks cause difficulty in deleting rows but they are completely destructible upon line completion: they represent mutations that can be auto-fixed by our cells (Figure 6.5 – a, b). The third brick, instead, has a geometry that does not fit in the existing lines without leaving any space: the line will never be completely deleted. Every time that one of these blocks is spawned, one row of the Mutan-Tetris becomes indestructible, reinforcing the message

that not all the mutations can be fixed by our cells (Figure 6.5 - c).

The game has been parametrized with several levels of difficulty, modifying the appearance probability of the new "mutated" bricks, giving the possibility to explore all the serious game contents. If the player is not able to achieve the minimum score, required to trigger the appearance of the mutated pieces, the game starts again informing that the level chosen is too difficult and suggests retrying with an easier level. The game ends when no more lines can be filled and deleted and there is no more space for new bricks in the playing field. The full playing field with the presence of unfixed/damaging mutations represents an incoming condition that could affect the cell health.

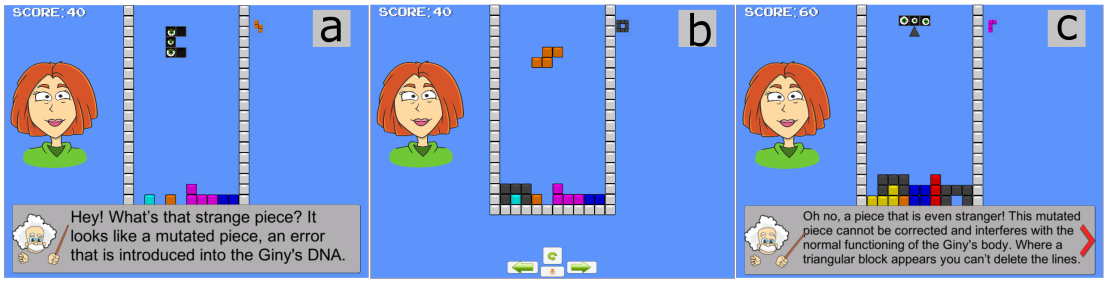


**Figure 6.5:** *The Mutant-Tetris. The classical Tetris is enriched with several new mutated blocks. The blocks represent the genetic material and the elimination of a row represents the correct encoding of the DNA. In figure a and figure b, the two fixable mutated bricks increase the difficulty in deleting lines. In figure c the mutated brick has a geometry that does not allow in any way the deletion of rows.*

## 6.3 Gene Adventure

Gene Adventure is an Adventure Serious Game designed to explain the concept of genetic risk and to show that in some cases (e.g. cardiovascular genetic risk) it is possible to manage it by adopting a lifestyle as healthy as possible. The game takes place in a small city (Risky-City) with several facilities (markets, restaurants, pub, park, etc.) where the player lives his everyday life. In this adventure game, the player embodies a young adult named Eugene, living his everyday life after having decided to undergo a DTC genetic testing (Figure 6.6 - a). During the concept phase, the aspects related to the psychological impact of genetic risk information were analysed and, based on this, narration, dialogues, situations and health-related choices were created to reproduce a simula-

tion experience as realistic as possible. The dramatic curve of the story should guide the player through several events and provide the "why" for the game, stimulating involvement and motivation. The plot follows an emotional arc that serves to motivate and involve the player during this learning journey. Coupling dramatic narrative with user interaction leads to the generation of forms of high engagement and immersion [97]. During the game, Eugene learns about the presence of some gene variants and his risk of developing cardiovascular diseases (Figure 6.6 - b).

Unfortunately, he cannot manage the significance of this kind of information and its implications; he has several chances to get more clarification about his health and the consequences of his genetic result. The player must help Eugene to find the best way to manage his cardiovascular risk by accomplishing several sub-tasks, making health-related decisions (Figure 6.7), modulating lifestyle and interacting with other characters.

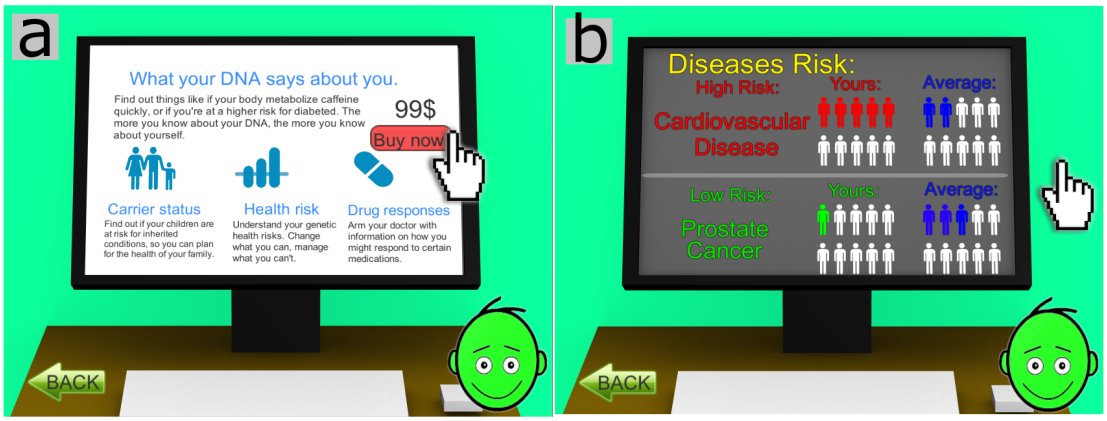


**Figure 6.6:** *Eugene is going to buy a Direct To Consumer Genetic Test online(a). After a while he receives the results of the test, discovering his high risk for cardiovascular disease.*

Every choice that the player is supposed to take throughout the game session has three possible alternatives, translated into avatar's behaviours, and each of them has a score between -1 (unhealthy choice) 0 (neutral choice) and +1 (healthy choice). The taken choice is simultaneously translated into a clear feedback: a modification of the colour and expression of a "smile icon" representing Eugene's health state and Quality of Life (Figure 6.8). The three alternatives included in each choice are formulated in a way that refers either to recurring behaviours (they

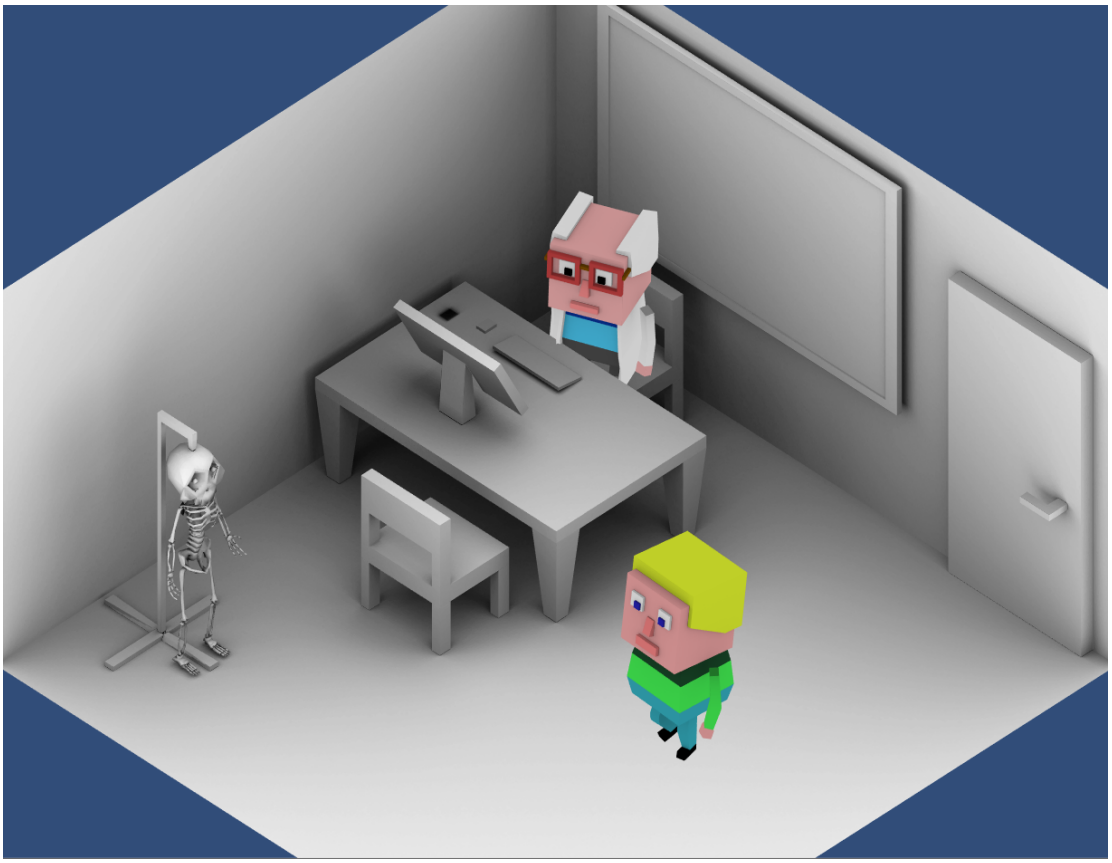

**Figure 6.7:** *The player chooses if Eugene must talk to his doctor about cardiovascular disease and genetic risk.*

reflect habits) or to occasional behaviours (they reflect just one occurrence), to give the idea that some behaviours could be problematic if they are repeated over time, and that some others are problematic even if occasional. In-game assessment of knowledge transfers and learning progress: Play-based assessment has been implemented through an algorithm that allows us to record player's decision-making changes and progress (how they accumulate points and experience, how they face new topics) during the adventure game session. A logging system was developed to keep track of the actions taken during the game. This way it is possible to evaluate the player's performance in 4 domains:

1. Physical Activity (see Figure 6.10)
2. Nutrition (see Figure 6.9)
3. Risk Behaviours (see Figure 6.6)
4. Stress management and social interactions (see Figure 6.7).

The system keeps track of the players' choices and the final score is converted into an informative and evaluative feedback. A composite description of the player's performance, its implications for health, and a final informative summary concerning genetic risk management will constitute the end of this educational journey. The player, this way, can understand whether she was good enough in managing Eugene's cardiovascular risk. We planned that the education journey time for a first-time player should be typically about 30 minutes.

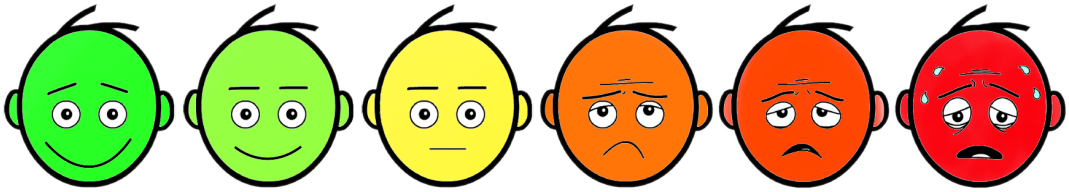

**Figure 6.8:** *The "smile icons" colours and expressions represent Eugene's health status.*

A summary is presented for each specified domain, in which additional useful information about cardiovascular risk management is also provided. To make clear to the player, in an intuitive way, if the choices made were valid, a colour code assigned to the background of the sign,


**Figure 6.9:** *During the adventure the player should carefully choose what to eat, this to maintain correct nutrition habits.*

**Figure 6.10:** *During Gene Adventure Eugene should carefully choose how to manage physical activity to maintain a good life-style.*

on which the report appears, has been established. The red colour indicates that deeply wrong choices were made and draws attention to which were the wrong choices during the game session, explaining why that choice was wrong. Through the yellow colour instead, we highlight a partially correct behaviour, we give guidance to the player on what went well and what didn't, also in this case by providing explanations on the behaviour during the game and on the best way to behave. Finally, with the green colour, we indicate to the player their ability to have correctly made optimal choices for the protagonist of the game. Even if the choices made were good we have chosen to add the explanation of why the choices made were optimal for the management of the health during the game.

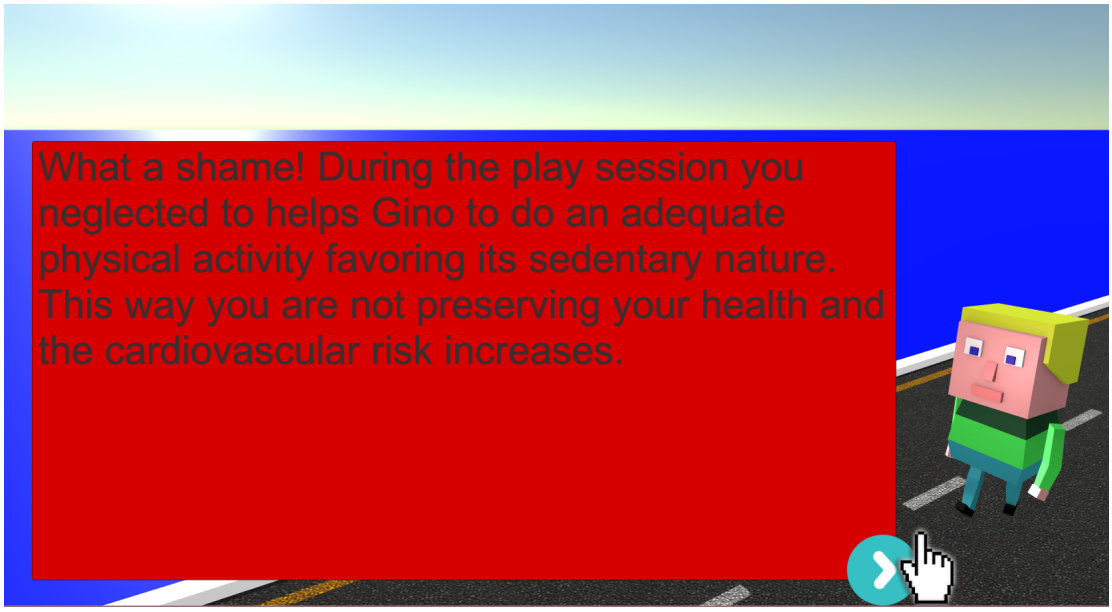


**Figure 6.11:** *The report given to the player at the end of the game. The button required to proceed is positioned at the bottom of the report, to encourage the player to read and not to skip the text.*

As a final note on the summary provided to the player, it's interesting to discuss how the interaction model was slightly modified in this last step compared to the rest of the game. Throughout the game, the virtual storyteller interface requires the player to click on the text to advance in the dialogue and to proceed to the next steps, this choice was successful and appreciated by users for its clarity and simplicity. However, proceeding in this way throughout the game leads to automating this process and

risks making the new information read hastily. It was therefore decided to change the mode of user interaction in the last and important phase of the analysis of the results. As you can see in Figure 6.11, to proceed to the next step the user can no longer press on the text of the virtual narrator but is obliged to press on the arrow placed after the explanation of the choices made. This modification leads to a more careful reading of the text, avoiding the automatism mentioned above.

## 6.4 Knowledge Transfer and Self Efficacy promotion through our Serious Games

Current generations have been raised in a digital world and have a natural attitude toward the digital language of computers, video games and the Internet. Young people spend a significant amount of time playing computer games where they usually experience a high level of motivation and engagement. For this reason, they find traditional learning a very complex task that requires a lot of effort and is incredibly boring [98].

To improve the appeal of our materials and to motivate and engage public interest in genetic concepts, challenging activities and clear educational goals were embedded in our games to guarantee pleasure and "flow" (a situation of complete absorption or engagement [79]- [94]- [95]- [96], which are relevant dimensions for SG efficacy. In our study, the serious games sought to maximizing genetic learning by both presenting individuals with genetic information and asking them to apply such information in order to successfully proceed with the game.

Learning process arose from several components of our games. First of all, genetic concepts are introduced and explained in a conversational way by a virtual narrator during an initial interactive tutorial. The virtual narrator is named SCI and accompanies the player through the tutorial, where the learner starts to know the characters, the elements and the main rules of the game, and where specific genetic mechanisms are discussed. Then, during all the game sessions, the character provides information, hints and feedbacks to ensure that players don't get stuck during the game (because of lack of understanding) or to better consolidate some concepts explained in the tutorial. Immediately after having listened and interacted with SCI, learner/player must overcome challenges applying

the basics of genetics. In this way, the learner/player has the opportunity to practice with the application of the genetic concepts in order to win the game.

While creating the game, we balanced the level of complexity of the genetic concepts with the game challenge and the required cognitive load, giving the player enough time to reflect and re-elaborate the rules of genetic mechanisms explained with the tutorial. We did it by introducing different levels of difficulty, alternating moments of challenge and reflection, and introducing hints from SCI.

Regarding the Adventure game, to successfully proceed with it (e.g. to maintain the principal character in good health condition, it is necessary that players adapt what they learned during the game session to each specific situation in the narration. Another important aspect we considered in SG design was to provide users with clear and immediate feedback (audio and video) about their performance.

We followed Piaget's principles of assimilation: (the player fits "new information" about genetics into existing slots or categories she had before playing), accommodation (the player accommodates "new information" about genetics that does not fit into an existing slot or category), and cognitive disequilibrium (presence of contradictory beliefs) to support learning process [99].

The challenge is to create a cognitive disequilibrium (a situation where the new information is not immediately interpretable based on existing categories), without exceeding the capacity of the player to succeed. Player try to find a new equilibrium by modifying their cognitive patterns by incorporating the newly acquired knowledge and thus interact with the game based on the new (genetic) mechanisms learned during the tutorial (testing) and finds out the result of this interaction through the immediate feedback (revision).

The feedback guarantees the ability to understand the results of the action taken during the play session.

## 6.5 A possible approach to the integration of the mini-games into the Adventure Game

Part of the project was to find the contents and methods necessary to convey the message about the DTC-GT, to provide users with enough information to make informed choices about the topic. We have chosen to implement a solution based on two different levels. The first level is related to the basic concepts of genetics, required to have a solid base about the nature of the problem, while the second should be more experiential to give to the player the opportunity to experience situations and emotions related to genetic testing.

This choice has led to the generation of different mini-games with the aim of transmitting targeted content that allows the player to understand the concepts of genetics needed to then be able to handle situations revealed by the execution of possible genetic tests. For example, the concept of inheritance illustrated through the game HeredyRabbit allows you to understand how the dominant and recessive characters are passed on to subsequent generations. This example of basic content, for example, can be used when a genetic test reveals to a patient that he or she is a carrier of cystic fibrosis, the most common serious genetic disease.

This disease is recessive and can therefore only be manifested if both parents are carriers. In Italy, for example, there is one healthy carrier for about 25 people. A couple of healthy carriers, with each pregnancy, has a probability of having one sick child in four. Playing the game we developed, the player should have acquired enough information through the game to help him understand that if his test was positive for cystic fibrosis disease it would be good to discuss with his partner about possible risks that could arise after a pregnancy. Basic knowledge of inheritance, therefore, helps people to make more informed decisions about how to act for the better, or at least to deepen their understanding of the subject in a critical way.

A choice that would come to be placed in a plausible scenario like the one described, in addition to requiring specific skills on a subject of genetics also requires the ability to know how to properly handle the emotions and stress of the situation to communicate with the partner in the most appropriate way. For this reason, we have introduced the graphic

adventure that has the exact purpose of simulating real-life situations in which the player must find the best strategy to manage the complex interpersonal situations that he has to face.

The architectural choices made, mini-games and adventure games, to cover the different skills required in these situations has led to the generation of content difficult to integrate under one roof. This distinction, however, risks making the player see these topics as separate, disjointed and independent of each other.

To try to remedy this situation it was decided to propose a possible solution including the mini-games based on specific genetic issues within the adventure game. In this way, the player has all this content available in a single integrated application that collects all the notions necessary to make personal choices as conscious as possible.

In the culture of video games, a similar technique has been widely used to enrich the experience of a player, typically limited by the boundaries of the narrative of the game he is playing. To achieve this, other sub-games are made available within the game that can be played by the player during the main game. For example, in the GTA series, it is possible to carry out activities not strictly related to the development of the main plot, such as playing golf, running races, etc. Also in other famous graphic adventures such as "The day of the tentacle" it is possible to play a complete sub-game "Maniac Mansion" through a computer located inside the game. This technique provides players with the opportunity to experience content normally unrelated to the main game, thus keeping the thread of the narrative.

Following this approach, we thought of a possible implementation, not yet tested, that includes the various mini-games with high genetic content inside a game room, located in the town where the adventure game is set. Players can decide to go to that building and using arcade cabinets play all the mini-games we developed (Figure 6.12).

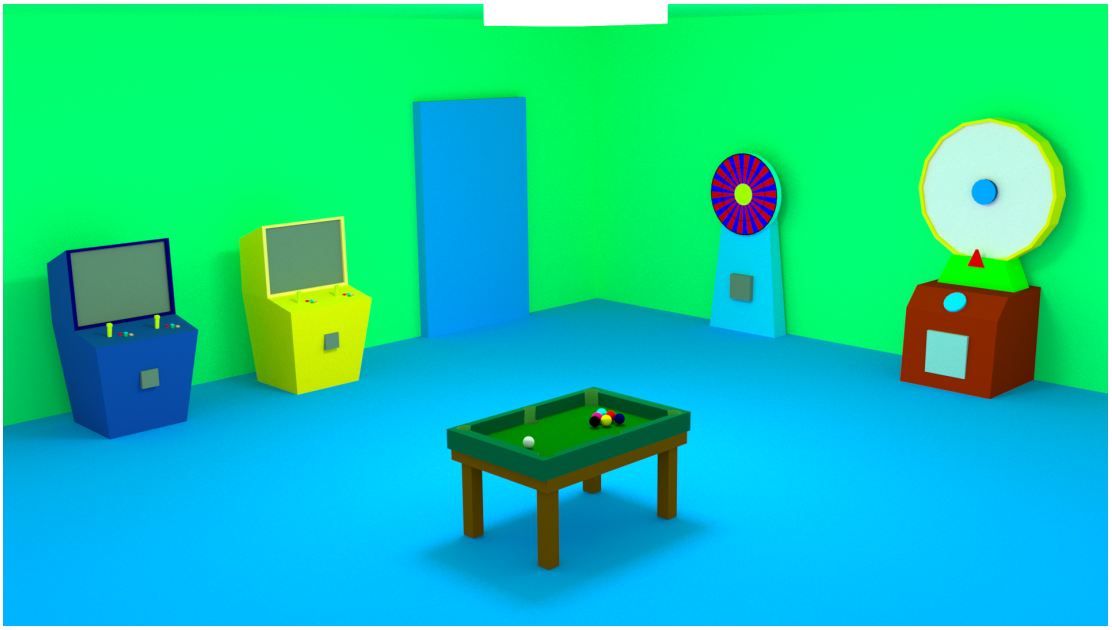

**Figure 6.12:** *The proposed solution to integrate under one roof all the mini-game experiences and the adventure game. This is in order to make these two different contents as integrated as possible. The Players, while playing the adventure game, can decide to go to the game room and play all the mini-games developed to teach basic genetic concepts.*

CHAPTER 7

# Defining the experimentation protocol to test the games

> It's not an experiment if you know it's going to work.
>
> Jeff Bezos

The development of every product, a SG with educational purposes in this case, must be subjected to a testing phase, as discussed in the methods section (Chapter 5). This quality process is done to ensure the usability of the product made by the end users and evaluate its concrete effectiveness.

## 7.1 What to test

With regard to software and specifically video games, the type of testing required to assess the ability of end users to use the product is the usability/playability test.

To assess whether the product developed achieves the objective for which it was made, in our case the transfer of knowledge, it is required to measure knowledge pre and post the playing session.

If, after the playing session, the measured knowledge is increased, then this would mean that the game was able to make the player learn at least part of the content for which it was developed. This requirement is very important in the field of games for learning, as well stated by Mayer in his book "Computer Games for Learning: An Evidence-Based Approach" [44].

Let's now better define the basis on which these types of tests are based on and describe the experiments that have been carried out during the testing phase of the games developed.

## 7.2 Test for playability

As a first step, we aim to assess games usability. Usability is defined in the ISO 9241-11 as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [100].

According to the literature [101], usability testing is important for SG, particularly for those that are designed to be used by heterogeneous population, including individuals that might not be accustomed to interact with new technologies (i.e., "non-gamers"). Basically, there are two main approaches to assess usability: observational analysis, in which a user interacts with the system while the developers observe and take note of every significant player-game interaction or player's comment; survey-based method, in which the user fills in evaluation questionnaires after the game session [102]- [103]- [104].

However, even though several scales have been developed (e.g. the System Usability Scale (SUS) [105] and the Questionnaire for User Interaction Satisfaction (QUIS) [106]), to date there are no validated scales to assess games usability. Therefore, we decided to perform a mixed method combining observational analysis of participants and a self-report questionnaire, the Game Experience Questionnaire, to partially overcome the current limitations of quantitative methods [107]. The observational analysis consists of recording the participants' reactions while they are playing, with a particular attention on what they say, and any emotional reaction (laugh, groan, frustration, doubts on how to proceed, etc.) in order to collect real-time information that may not be captured

by post-test surveys [108]. Observational analysis allows researchers to note the overall engagement of the player: deep engagement in serious games has been associated with learning and students' academic achievement [109]- [110]. Engagement refers to a holistic experience, a mixture of involvement and enjoyment; it is a key factor for a SG and determines the effectiveness of learning. Several measures have been applied in literature for slightly different aspects of engagement in SG: scales of immersion and presence [111], flow [112], and engagement [113]. The most fitting questionnaire for our SG is the Game Experience Questionnaire [114] because it measures how players' feel during the game session. It is composed o 33 items and assesses seven core dimensions: Immersion, Flow, Competence, Positive and Negative Affect, Tension, and Challenge. For each item, participants must state their personal experience on a five-point Likert scale (from 1 not at all, to 5 extremely).

### 7.2.1 Experiment Description

Participants were assigned to one of the three games. They dealt with the game individually. Before interacting with the game, they completed an informed consent form. Participants received brief instructions about the game and were prompted to play on their own, without any further direction or instruction. They were also asked to speak loudly while playing, to express their thoughts. At the end of the play session, participants reported any issues, both negative and positive, they found during play and were invited to complete the Games Experience Questionnaire. Programmers were then allotted time to address and fix the problems that emerged.

## 7.3 Test for knowledge transfer and self-efficacy

As the purpose of a serious game is to increase the user's knowledge and/or self-efficacy, it is essential to assess the individuals' learning outcomes. Most studies evaluated SG effectiveness using pre-test and post-test [115], whereas in some other cases a control group of individuals who received the target information through other instructional techniques has been used. We decided to use both assessment methods.

### 7.3.1 Target population and recruitment

To test whether learning goals have been achieved, a total of 60 teenagers and adults, all volunteers, with an age ranging between 16 and 65 years will be enrolled: 30 participants will be assigned to the experimental group and 30 participants to the control group. Participants in the two groups will be balanced by age and gender. All participants will be recruited from the general population using author's e-mail and social media contacts, posters emailed to all University of Milan staff and students, as well as via personal invitation and snowball sampling. The invitation will contain a brief description of the tasks, the median amount of time required, and contact information.

### 7.3.2 Experiment description

Before starting the game session, participants will complete a demographic questionnaire on age, gender, education level, previous experience with computer/mobile/tablet devices, and habits related to playing video games. Participants with no experience with technological devices will be excluded. Participants enrolled (both experimental and control groups) will deal with the following steps:

1. Knowledge-transfer pre-test questionnaire: an ad hoc questionnaire to assess genetic topic-specific knowledge, with questions concerning Mendel's laws, mutation and genetic risk implications in particular. It is composed of multiple-choice questions or true/false questions e.g.:

   "From a pair of rabbits with Cc and cc genotype respectively, what is the proportion of their children's genotypes":

   - A) three CC rabbits and one Cc
   - B) three Cc rabbits and one CC
   - C) two Cc rabbits and two cc
   - D) four rabbits cc

   or:

   "A healthy lifestyle can prevent or lessen the negative consequences of having genetic predispositions to some diseases (True/False)".

Participants who will correctly answer more than 80% of the questions in the pre-test will be excluded from the study, due to the high base-rate literacy in genetics and genetic risk information.

2. Self-efficacy pre-test questionnaire: a questionnaire which assesses their perceived self-efficacy with genetic knowledge, defined as confidence in one's ability to use genetic information. The questionnaire comprised 8 items, to be answered through a 5-point Likert scale such as: "I am able to understand information about how genes can affect my health", and "I am able to explain to others how genes affect one's health".

3. Serious games playing session/paper-based information reading: Participants will then be allocated to either the experimental group, that will play the serious games or the control group, that will receive leaflets with the very same information of the experimental group (traditional paper-based approach for learning). Participants in the experimental group will play the two mini-games first (the Heredi-Rabbit and the Mutan-Tetris), to start from the basic concepts of genetics, and then will move on to the Gene Adventure, which introduces some concepts on genetic risk. The game session will last overall 50 minutes approximately. The control group will have about 50 minutes to read the genetic information in the leaflets, which are, for instance, those given in the games by the virtual narrator. An example of content: "Each gene has at least two variants, called alleles. One allele comes from the mother and the other allele comes from the father" (see Figure 1-a for the corresponding content in the game Heredi-Rabbit) or "Some mutations have no effect; some could be auto-fixed by the organism; others could provoke illness, sometimes serious (like cancer)". As the primary aim of our study is to investigate the efficacy of the SG, we believe a media comparison is paramount to verify if knowledge-transfer depends on the kind of tool applied.

4. Knowledge-transfer post-test: At the end of the game session the experimental group and leaflets readers (control group) will be presented with the post-test questionnaire (with the same questions embedded in the pre-test questionnaire) to assess genetic topic-specific

knowledge. Significant differences between the test scores in both groups will be indicative of knowledge transfer efficacy. Furthermore, differences in the delta between pre-and post-test between the two groups will reveal differences in the efficacy of SG compared to traditional paper-based information.

5. Finally, participants from both groups will be asked again to fill in the self-efficacy questionnaire. The differences between pre-and post-test self-efficacy will suggest a greater confidence in one's own knowledge.

CHAPTER 8

# Playability test results

> People ignore design that ignores people.
>
> Frank Chimero

The study sample consisted of 30 participants, all volunteers, selected from the general public, with no particular education restriction in the field of genetics, with an age ranging between 18 and 60 years. The enrolment process paid attention to balance the presence of 15 younger (under 30 years old) and 15 older (over 30 years old) participants. Each subgroup of 15 participants has then been randomly divided into three subgroups (5 participants each), assigned to play one of the three games. Consequently, we obtained three experimental groups, each including 10 participants.

The age threshold was chosen to roughly split between people that grew up familiar with arcade games (golden age 1978-1986) and not. This is to investigate possible differences in the game experience, playing the MutanTetris game between the two aged players populations.

All evaluation sessions took place in a quiet room at the University of Milan, in presence of the experimenter. As the first task, each participant completed a demographic questionnaire on age, gender, education

level, previous experience with computer/mobile phone/tablet devices, and habit of playing video games.

**Table 8.1:** *Socio-demographic characteristics of game players and frequencies of devices and video games use.*

| **Characteristics** | | **Rabbit N** | **Tetris N** | **GeneAdv. N** |
|---|---|---|---|---|
| **Gender** | | | | |
| | **Male** | 4 | 6 | 5 |
| | **Female** | 6 | 4 | 5 |
| **Education** | | | | |
| | **Elementary High School** | 1 | 0 | 5 |
| | **University College** | 9 | 10 | 5 |
| **Experience with computer tablet, smartphone** | | | | |
| | **Never** | 0 | 0 | 0 |
| | **Rarely** | 0 | 0 | 0 |
| | **Sometimes** | 1 | 1 | 3 |
| | **Often** | 4 | 4 | 6 |
| | **Always** | 5 | 5 | 1 |
| **Experience with videogames** | | | | |
| | **Never** | 2 | 4 | 0 |
| | **Rarely** | 3 | 1 | 4 |
| | **Sometimes** | 5 | 2 | 3 |
| | **Often** | 0 | 0 | 3 |
| | **Always** | 0 | 3 | 0 |
| **Age medium (range)** | | 37 (21-54) | 41 (23-60) | 35 (20-60) |

The experimenter guided the participants through the testing procedure but did not intervene to avoid disrupting their autonomous thinking process. In particular, participants were told not to ask the experimenter advice on how to play, nor help to face game challenges. On the contrary, they were asked to report to the experimenter any difficulty in interacting with the system (e.g., in selecting images, reading the text, continuing with the text, interacting with game characters, understanding the tasks to be played during the game, etc.) and any error they could detect, as they experienced such difficulties.

The experimenter took note of every player comment and observation provided during the game and of any observed difficulty in the player game session system interaction. After playing the game, the participants were asked to fill out the Games Experience Questionnaire (GEQ) [114]. The questionnaire includes 33 items divided into 7 dimensions: competence, immersion (feeling involved/interested by the game challenges and contents), flow (feeling a complete absorption or engagement in the activity [79], tension/annoyance, challenge, negative affect, positive effect. All questions were answered on a 5-point Likert scale that was anchored by "Not at all"(0) and "Extremely"(4). Game sessions usually lasted about 30 minutes.

## 8.1 Results

The qualitative analysis of the usability testing revealed the presence of some design and functionality issues that could affect the effective and efficient use of the games. To classify such issues, a set of 8 usability heuristics was used, specifically created by Bertini et al. [116] to evaluate mobile computing applications. Three researchers discussed each issue reported by participants in order to assign it to a specific heuristics. All the issues belonged to one of the following two heuristics:

- Heuristic $3-$Consistency and mapping: The user's conceptual model of the possible function/interaction with the mobile device or system should be consistent with the context. It is especially crucial that there is a consistent mapping between user actions/interactions (on the device buttons and controls) and the corresponding real tasks.

- Heuristic $5-$Ease of input, screen readability and glanceability: mobile systems should provide easy ways to input data, possibly reducing or avoiding the need for the user to use both hands. Screen content should be easy to read and navigate through notwithstanding different light conditions. Ideally, the mobile user should be able to quickly get the crucial information from the system by glancing at it.

Results showed 6 usability issues for the HerediRabbit (Table 8.2), 5 usability issues for MutanTetris (Table 8.3) and 4 usability issues for

Gene Adventure (Table 8.4). Each of the identified issues was mapped to source events (i.e. errors, requests for help, participant's concurrent feedback, and moderator observation) used to identify the issue.

In the HerediRabbit most usability issues concerned the consistency and intuition of commands (7 players in total) to proceed during the game and their readability (2 players). 4 players also reported system errors when at the end of one play session, another session must start with a new game goal. In the MutanTetris the majority of usability issues concerned the consistency between user actions/interactions on the game commands and the corresponding tasks (all the 10 players). It was difficult for all the players to understand the meaning of the bent arrow button, used to rotate the pieces inside the game. For Gene Adventure the most common problem concerned the commands and goals needed to accomplish the corresponding tasks in the game or to proceed in subsequent actions. The commands were sometimes unclear/poorly intuitive or were not associated with the corresponding "real" tasks in the game (i.e. people did not want to buy the genetic test but after some minutes understood they could not continue in the game without buying it, 9 players). Additionally, the feedback provided by 5 players highlighted how the alternatives proposed by the game did not allow intermediate choices.

**Table 8.2:** *HeredyRabbit usability issues.*

| ***Problem*** | ***Source (frequency)*** | ***Heuristic*** |
|---|---|---|
| Text readability | Feedback (2) | 5-Ease of input screen readability and glanceability |
| Clouds deceive | Feedback (1) | 5-Ease of input screen readability and glanceability |
| Commands to continue the game are not intuitive | Feedback (1) | 3-Consistency and mapping |
| Shift from one game session to another | Observation (4)<br>Feedback (4) | 5-Ease of input screen readability and glanceability |
| Continue after questions not intuitive | Observation (3) | 3-Consistency and mapping |
| Start the game is not intuitive | Observation (2)<br>Request for help (1) | 3-Consistency and mapping |

**Table 8.3:** *MutanTetris usability issues.*

| ***Problem*** | ***Source (frequency)*** | ***Heuristic*** |
|---|---|---|
| The descriptive commands are not clear | Feedback (3) | 3-Consistency and mapping |
| Commands to continue the game are not intuitive | Observation (5) Request for help (2) | 3-Consistency and mapping |
| The commands don't work | Feedback (1) | 3-Consistency and mapping |
| The final aim of the game is not clear | Feedback (2) | 3-Consistency and mapping |
| Commands are not evident | Feedback (3) Observation (2) | 5-Ease of input screen readability and glanceability |

**Table 8.4:** *GeneAdventure usability issues.*

| ***Problem*** | ***Source (frequency)*** | ***Heuristic*** |
|---|---|---|
| Commands to continue in the game are not intuitive, or they are not evident or they do not correspond to the task in the game | Observation (7) Request for help (2) | 3-Consistency and mapping 5-Ease of input screen readability and glanceability |
| Some elements of the game are poorly visible (the smile icon) | Observation (1) | 5-Ease of input screen readability and glanceability |
| The goals of the actions in the supermarket are not clear (how many products do I have to buy?) | Observation (2) | 3-Consistency and mapping |
| Alternatives proposed do not allow half-way choices | Feedback (5) | 3-Consistency and mapping |

Another frequent feedback players reported to the experimenter was that the alternatives proposed by the game often did not match what they would choose to do in real life (e.g. going to a romantic restaurant with a girlfriend by bike instead of by car). Players admitted that their choices were based on preserving Eugene's health status, but that they didn't always correspond to how they would have acted for themselves.

All these issues have been considered and solved in the subsequent software release. Because no critical usability problem was found, the new fixed version will be directly used in the next knowledge transfer

**Table 8.5:** *Mean and Standard Deviation(SD) scores for Competence, Immersion, Flow, Tension, Challenge, Negative Affect and Positive Effect in HeredyRabbit, MutanTetris and Gene Adventure-Wt players.*

| | | *Competence* | *Immersion* | *Flow* | *Tension* | *Challenge* | *Negative affect* | *Positive effect* |
|---|---|---|---|---|---|---|---|---|
| | | Mean (SD)Mean (SD) | | | | | | |
| ***HeredyHeredy Rabbit Rabbit*** | **total** | 2.04 (0.91) | 1.90 (0.62) | 2.28 (0.84) | 0.2 (0.36) | 0.62 (0.53) | 0.025 (0.08) | 2.34 (0.78) |
| | **under 30** | 2.16 | 2.03 | 2.28 | 0.33 | 0.72 | 0.05 | 2.4 |
| | **over 30** | 1.92 | 1.77 | 2.28 | 0.07 | 0.52 | 0 | 2.28 |
| ***MutanMutan Tetris Tetris*** | **total** | 1.08 (0.83) | 1.93 (0.89) | 2.22 (1.12) | 0.13 (0.28) | 1.1 (0.57) | 0.25 (0.44) | 2.14 (0.82) |
| | **under 30** | 0.68 | 1.93 | 2.52 | 0.13 | 1.16 | 0.1 | 2.0 |
| | **over 30** | 1.48 | 1.93 | 1.92 | 0.13 | 1.04 | 0.4 | 2.28 |
| ***Gene Gene AdventureAdventure*** | **total** | 2.06 (0.43) | 2.28 (0.47) | 2.00 (0.48) | 0.17 (0.32) | 0.68 (0.48) | 0.18 (0.26) | 2.36 (0.66) |
| | **under 30** | 2.20 | 2.27 | 1.80 | 0.13 | 0.88 | 0.25 | 2.12 |
| | **over 30** | 1.92 | 2.30 | 2.20 | 0.20 | 0.48 | 0.10 | 2.60 |

test experiment.

To evaluate whether participants were comfortable with, or enjoyed playing the games, their answers to the GEQ sub-scales were analysed. Mean scores of the game players' responses to the GEQ sub-scales are shown in Table 8.5.

Participants who played the MutanTetris game reported low levels of competence (M=1.08 corresponding to "slightly" on the Likert scale), whereas they perceived to have more ability in playing the jump and run game HerediRabbit and the Gene Adventure game (M=2.04 and M= 2.06 respectively, corresponding to "moderately" on the Likert scale). The levels of immersion and flow were moderate for all the games (mean values approximately corresponding to "moderately" on the Likert scale). Very low levels of tension/annoyance were registered, thus revealing that the games did not create a situation of frustration or annoyance. The level of challenge was slightly higher for the MutanTetris (M=1.1), describing that players felt more pressure and effort investment to face Tetris challenge, whereas in HerediRabbit and Gene Adventure the difficulty levels and time available to finish the required tasks had been perceived as appropriate. Lastly, players reported to have experienced roughly no

negative affect; on the contrary, they reported medium-high positive effect playing the games. There were no significant differences between younger and older players (under 30 years old vs. over 30 years old) in the GEQ sub-scales concerning the different games (U Mann Whitney $.115 < p < .819$), excluding competence and flow related to MutanTetris. Indeed, older players (over 30 years old) felt more expert in playing Tetris, whereas younger players felt more absorbed by the game challenge. There was no significant difference in the frequency of video games use based on the age range. Participants were all frequent users of computers, tablets, and smart phones. Dividing the players based on how much they used to play video games (values 1-2 on the Likert scale corresponding to low frequency, 3-5 corresponding to high frequency) no significant differences emerged for any game between the two groups in all the GEQ sub-scales (U Mann Whitney $.068 < p < .658$).

CHAPTER 9

# Testing Knowledge Transfer and Self Efficacy

They are able who think they are able.

Virgilio

The analysis of the results of the preliminary study, presented below, was carried out on a sample of twenty participants. This preliminary study was carried out to test the efficacy of the games developed and to test the sensitivity of the knowledge transfer test and the sensitivity of the self-efficacy test.

The decision to start with a small sample was made because each tester takes about 1 hour and a half to complete the whole test, so the execution of the complete test requires more resources than were available. It was therefore decided to start with a preliminary test so as to have feedback on the proper functioning of the experiment before spending the considerable time and resources necessary to perform the complete test on the entire sample presented in the protocol of the experiment (Chapter 7.3).

## 9.1 Preliminary results about Knowledge Transfer

The number of correct answers of the knowledge transfer questionnaire for each player, filled in before and after the game session, is reported in Table 9.1. In the last column of the table the Difference has been evaluated, and represents the difference between the player knowledge pre-test and post-test:

$$Difference = (Pre - Post) \tag{9.1}$$

In all cases, except one, the value is negative, this means that the sample of players tested has been able to respond better to the questions related to genetics after playing the games.

To evaluate the statistical significance of the results obtained, however, it was decided to carry out a Paired T-Test as a statistical analysis and to evaluate the Effect size to assess whether the results obtained are also statistically significant.

**Table 9.1:** *The number of correct answers of the knowledge transfer questionnaire, filled in before and after the game session.*

| Player | Pre-Test | Post-Test | Difference = Pre - Post |
|---|---|---|---|
| 1 | 9 | 10 | -1 |
| 2 | 5 | 10 | -5 |
| 3 | 1 | 7 | -6 |
| 4 | 5 | 8 | -3 |
| 5 | 5 | 4 | 1 |
| 6 | 2 | 7 | -5 |
| 7 | 5 | 8 | -3 |
| 8 | 4 | 7 | -3 |
| 9 | 8 | 9 | -1 |
| 10 | 3 | 8 | -5 |
| 11 | 3 | 3 | 0 |
| 12 | 2 | 7 | -5 |
| 13 | 9 | 8 | 1 |
| 14 | 5 | 7 | -2 |
| 15 | 6 | 7 | -1 |
| 16 | 7 | 6 | 1 |
| 17 | 7 | 9 | -2 |
| 18 | 3 | 6 | -3 |
| 19 | 2 | 5 | -3 |
| 20 | 5 | 7 | -2 |
| | | | |
| Average | 4.8 | 7.15 | -2.35 |
| St. Dev. | 2.353 | 1.785 | 2.159 |
| n | 20 | 20 | 20 |

From the sample data, it is found that the corresponding sample means and standard deviations are (Figure 9.1):

$$\bar{X}_1 = 4.8$$

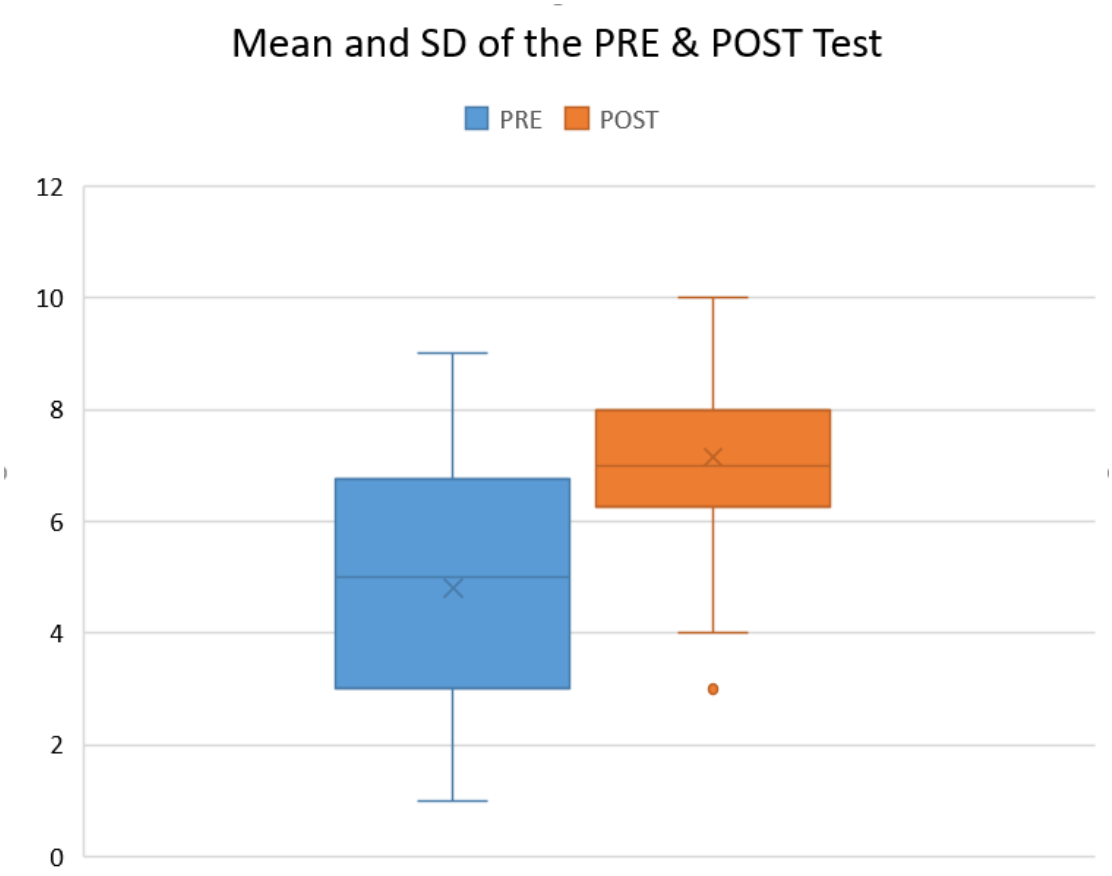


**Figure 9.1:** *Mean and Standard Deviation of the PRE and POST Test.*

$$\bar{X}_2 = 7.15$$

Also, the provided sample standard deviations are:

$$s_1 = 2.353$$

$$s_2 = 1.785$$

and the sample size is $n = 20$.

For the score differences, we have

$$\bar{D} = -2.35$$

$$s_D = 2.159$$

### 9.1.1 Statistical Analysis

The Paired T-Test is a statistical procedure used to determine whether the mean difference between two sets of observations is zero. If is zero it means that there are no significant differences between the two sets of observations.

In our case, if there is no difference between the two sets of observations means that games are useless to improve knowledge about genetics.

***(1) Null and Alternative Hypotheses***

The following null and alternative hypotheses need to be tested:

$$Ho : \mu_D = 0$$

$$Ha : \mu_D < 0$$

This corresponds to a left-tailed test, for which a t-test for two paired samples be used.

- The null hypothesis $Ho$ assumes that the true mean difference ($\mu_D$) is equal to zero. (No difference between the two sets)

- The left-tailed alternative hypothesis $Ha$ assumes that $\mu_D$ is less then zero. (Significant difference between the two sets: $\mu_1 < \mu_2$ means that the number of correct answers before playing the games is less then the number of correct answers after playing the games)

***(2) Rejection Region***

We choose to set the significance level at $\alpha = 0.01$, and the degrees of freedom are $df = 19$.

Hence, it is found that the critical value for this left-tailed test is $t_c = -2.539$, for $\alpha = 0.01$ and $df = 19$.

The rejection region for this left-tailed test is $R = \{t : t < -2.539\}$.

***(3) Test Statistics***

The t-statistic is computed as shown in the following formula:

$$t = \frac{\bar{D}}{s_D/\sqrt{n}} = \frac{-2.35}{2.159/\sqrt{20}} = -4.868$$

***(4) The decision about the null hypothesis***

Since it is observed that $t = -4.868 < t_c = -2.539$, it is then concluded that the null hypothesis is rejected.

Using the P-value approach: The p-value is $p = 0.0001$, and since $p = 0.0001 < 0.01$, it is concluded that the null hypothesis is rejected.

***(5) Conclusion***

It is concluded that the null hypothesis $Ho$ is rejected. Therefore, there is enough evidence to claim that population mean $\mu_1$ is less than $\mu_2$, at the 0.01 significance level. Usually at the $p < 0.05$ level, based on traditional measures of significance such as t-tests or analyses of variance, the result obtained is statistically significant.

***Effect Size***

$$d = \frac{t}{\sqrt{N}}$$

$$d = \frac{-4.868}{\sqrt{20}} = -1.089$$

It is useful to interpret Cohen's $d$ as a measure of the distance between two means and it represents the number of standard deviations between the two. "Cohen [117] has suggested that effect sizes below $d$ = 0.2 are negligible, at $d$ = 0.2 are small, at $d$ = 0.5 are medium, and above $d$ = 0.8 are large".

Hattie [118] has proposed that "any effect size greater than $d$ = 0.4 is educationally important" [44]. This means that with $d = 1.089$, the SG developed has a large effect size as far as the knowledge transfer part is concerned.

The sign of Cohen's $d$ depends on which sample means was label 1 and 2. If $\mu_1$ is bigger than $\mu_2$, the effect size will be positive and if the second mean is larger, the effect size will be negative.

The sign of $d$ effect represents the direction of the effect. Here $\mu_1$ represents the PRE Test and $\mu_2$ represents the POST Test, then a negative effect size indicates the effect increases the mean and as a result increase knowledge.

## 9.2 Preliminary results about Self Efficacy

The Tables 9.2 - 9.3 shows the values of a 5-point Likert scale chosen by the players before and after playing the games. The values range from 1 to 5 and represent the level of confidence that the player believes he has on issues related to genetics (1= totally confident 5=totally unconfident). The last two rows instead indicate how confident the player feels about having correctly answered the genetics questions.

Table 9.4 represents the score differences between pre and post values.

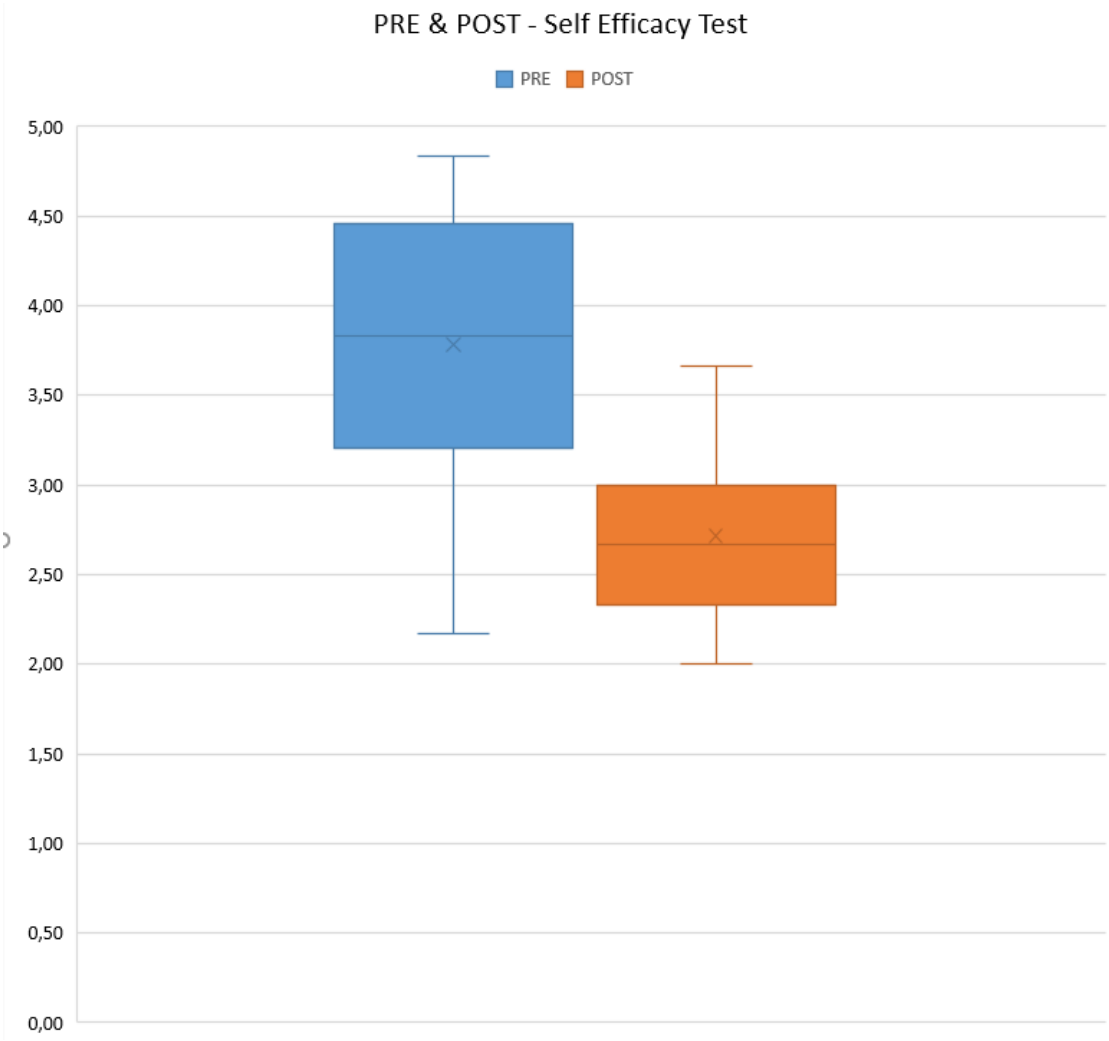


**Figure 9.2:** *Mean and Standard Deviation of the PRE and POST about the Self Efficacy Test.*

From the sample data, it is found that the corresponding sample means and standard deviations 9.2 are:

$$\bar{X}_1 = 3.784$$

$$\bar{X}_2 = 2.718$$

Also, the provided sample standard deviations are:

$$s_1 = 0.727$$

$$s_2 = 0.43$$

and the sample size is $n = 20$. For the score differences, we have

$$\bar{D} = 1.067$$

$$s_D = 0.582$$

### 9.2.1 Statistical Analysis

This time analysing the T-Test results, if there is no difference between the two sets of observations means that games are useless to improve self-efficacy about genetics.

***(1) Null and Alternative Hypotheses***

The following null and alternative hypotheses need to be tested:

$$Ho : \mu_D = 0$$

$$Ha : \mu_D > 0$$

This corresponds to a right-tailed test, for which a t-test for two paired samples is used.

***(2) Rejection Region***

We choose to set the significance level at $\alpha = 0.01$, and the degrees of freedom are $df = 19$.

Hence, it is found that the critical value for this right-tailed test is $t_c = 2.539$, for $\alpha = 0.01$ and $df = 19$.

The rejection region for this two-tailed test is $R = \{t : t > 2.539\}$.

***(3) Test Statistics***

The t-statistic is computed as shown in the following formula:

$$t = \frac{\bar{D}}{s_D/\sqrt{n}} = \frac{1.067}{0.582/\sqrt{20}} = 8.195$$

***(4) The decision about the null hypothesis***

Since it is observed that $t = 8.195 > t_c = 2.539$, it is then concluded that the null hypothesis is rejected.

Using the P-value approach: The p-value is $p = 0$, and since $p = 0 < 0.01$, it is concluded that the null hypothesis is rejected.

***(5) Conclusion***

It is concluded that the null hypothesis $Ho$ is rejected. Therefore, there is enough evidence to claim that population mean $\mu_1$ is greater than $\mu_2$, at the 0.01 significance level. We can conclude that also in this case playing games have allowed players to improve their self-efficacy in genetics.

***Effect Size***

$$d = \frac{t}{\sqrt{N}}$$

$$d = \frac{8.195}{\sqrt{20}} = 1.832$$

Also in this case with $d = 1.832$, the SG developed has a large effect size as far as the Self Efficacy part is concerned.

**Table 9.2:** *The scores of the self-efficacy pre-test.*

| Self Efficacy PRE-Test | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 | P14 | P15 | P16 | P17 | P18 | P19 | P20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I feel confident in my ability to understand topics related to genetics | 5 | 4 | 5 | 3 | 5 | 5 | 5 | 5 | 5 | 5 | 2 | 3 | 2 | 3 | 4 | 3 | 5 | 5 | 3 | 4 |
| I can understand information about how genes can affect my health | 3 | 4 | 3 | 2 | 5 | 5 | 3 | 4 | 3 | 5 | 2 | 3 | 2 | 3 | 3 | 2 | 5 | 5 | 4 | 3 |
| I have a precise idea of how genetics influences the risk of developing pathologies | 5 | 5 | 3 | 4 | 5 | 5 | 3 | 4 | 5 | 5 | 3 | 3 | 2 | 4 | 3 | 3 | 3 | 3 | 4 | 3 |
| I have a precise idea of how my genetic make-up can affect the risk of developing a pathology | 5 | 5 | 2 | 3 | 5 | 5 | 4 | 4 | 5 | 5 | 2 | 3 | 3 | 4 | 3 | 3 | 1 | 2 | 4 | 3 |
| I can explain to others how genes can affect a person's health | 5 | 5 | 5 | 3 | 5 | 4 | 5 | 4 | 5 | 5 | 4 | 4 | 2 | 5 | 3 | 5 | 5 | 3 | 5 | 4 |
| I have a precise idea of how my lifestyle can interact with my genetic make-up in influencing my health | 5 | 4 | 5 | 4 | 4 | 4 | 3 | 4 | 3 | 3 | 3 | 3 | 2 | 4 | 3 | 4 | 3 | 2 | 5 | 4 |
| With respect to the 10 questions you answered a moment ago about genetic knowledge, how many of them do you think you answered correctly? (indicate the number) | 3 | 3 | 0 | 5 | 1 | 1 | 2 | 2 | 4 | 5 | 6 | 5 | 6 | 2 | 4 | 5 | 3 | 0 | 2 | 1 |
| Referring to the number indicated in the previous question, how confident do you feel, in percentage, that you have answered those questions correctly? (indicate the percentage) | 50 | 50 | 12 | 80 | 20 | 26 | 70 | 64 | 30 | 40 | 75 | 86 | 50 | 13 | 60 | 75 | 50 | 100 | 80 | 25 |

**Table 9.3:** *The scores of the self-efficacy post-test.*

| Self-Efficacy Post-Test | P1 | P2 | P3 | P4 | P5 | P6 | P7 | P8 | P9 | P10 | P11 | P12 | P13 | P14 | P15 | P16 | P17 | P18 | P19 | P20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I feel confident in my ability to understand topics related to genetics | 3 | 3 | 3 | 2 | 3 | 3 | 2 | 3 | 3 | 4 | 2 | 2 | 2 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| I can understand information about how genes can affect my health | 3 | 2 | 2 | 2 | 3 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 3 | 3 | 3 | 2 | 2 | 3 | 2 |
| I have a precise idea of how genetics influences the risk of developing pathologies | 3 | 3 | 2 | 2 | 3 | 4 | 3 | 3 | 3 | 4 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 2 | 4 | 3 |
| I have a precise idea of how my genetic make-up can affect the risk of developing a pathology | 3 | 3 | 2 | 3 | 2 | 3 | 2 | 2 | 4 | 3 | 2 | 3 | 2 | 3 | 3 | 3 | 2 | 3 | 5 | 2 |
| I can explain to others how genes can affect a person's health | 3 | 3 | 3 | 3 | 4 | 4 | 3 | 4 | 4 | 3 | 3 | 3 | 2 | 3 | 3 | 3 | 3 | 2 | 4 | 2 |
| I have a precise idea of how my lifestyle can interact with my genetic make-up in influencing my health | 3 | 2 | 2 | 3 | 1 | 2 | 1 | 3 | 2 | 2 | 2 | 3 | 2 | 2 | 3 | 3 | 2 | 2 | 3 | 3 |
| With respect to the 10 questions you answered a moment ago about genetic knowledge, how many of them do you think you answered correctly? (indicate the number) | 7 | 9 | 3 | 7 | 6 | 4 | 7 | 4 | 8 | 7 | 7 | 6 | 7 | 4 | 5 | 6 | 6 | 3 | 4 | 6 |
| Referring to the number indicated in the previous question, how confident do you feel, in percentage, that you have answered those questions correctly? (indicate the percentage) | 70 | 75 | 69 | 92 | 60 | 39 | 96 | 89 | 71 | 80 | 78 | 94 | 60 | 77 | 50 | 60 | 85 | 92 | 20 | 50 |

**Table 9.4:** *Score difference of the Self-Efficacy test Pre & Post*

| Player | Pre-Test | Post-Test | Difference = Pre - Post |
|---|---|---|---|
| 1 | 4.67 | 3.00 | 1.67 |
| 2 | 4.50 | 2.67 | 1.83 |
| 3 | 3.83 | 2.33 | 1.5 |
| 4 | 3.17 | 2.50 | 0.67 |
| 5 | 4.83 | 2.67 | 2.16 |
| 6 | 4.67 | 3.17 | 1.5 |
| 7 | 3.83 | 2.17 | 1.66 |
| 8 | 4.17 | 3.00 | 1.17 |
| 9 | 4.33 | 3.17 | 1.16 |
| 10 | 4.67 | 3.17 | 1.5 |
| 11 | 2.67 | 2.17 | 0.5 |
| 12 | 3.17 | 2.67 | 0.5 |
| 13 | 2.17 | 2.00 | 0.17 |
| 14 | 3.83 | 2.83 | 1 |
| 15 | 3.17 | 3.00 | 0.17 |
| 16 | 3.33 | 3.00 | 0.33 |
| 17 | 3.67 | 2.33 | 1.34 |
| 18 | 3.33 | 2.33 | 1 |
| 19 | 4.17 | 3.67 | 0.5 |
| 20 | 3.50 | 2.50 | 1 |
| | | | |
| Average | 3.784 | 2.718 | 1.067 |
| St. Dev. | 0.727 | 0.43 | 0.582 |
| n | 20 | 20 | 20 |

CHAPTER 10

# Conclusion

"Begin at the beginning and go on till you come to the end: then stop."

Lewis Carroll, Alice in Wonderland

Since the launch of the Human Genome project in 1990, an educational imperative was recognized: to improve genetic literacy in the general public [119]. Overall, genetic literacy means to understand basic biological mechanisms (e.g. to know that DNA is our information molecule and determines our variation and diversity), understand elements of the personal and health implications of genetics, understand the interaction and interdependence of genes, the individual, and the environment [120]. Unfortunately, even well-educated people lack an understanding of these concepts [121]- [122]. The increasing impact of genetic testing [21] and the importance of decision making in disease prevention, makes it important to educate people in genetic matters. Without such knowledge, individuals are more likely to make uninformed decisions or to handover all decisions about genetic testing to their doctors. In this framework, technological innovations such as SG might become valid instruments to support public education and empowerment [121]- [123]- [124]- [125] and to prepare citizens for informed personal and societal

decision-making in genetics.

The contribution of this thesis was focused on the development of new technologies to improve literacy in lay people, trying to respond to some basic knowledge needs necessary to make informed medical decisions and illustrate the implications that these new direct-to-consumer genetic tests can have in our lives. With this work we were thus able to address the research questions we presented in the introductory chapter (see section 1.4): We defined what we believe are the pillars of genetics and we proposed technological solutions that can help the general public better understand genetic risk and genetic test results.

Two games were specifically designed for knowledge transfer about basic genetics concepts (heredity, mutation) and one for both knowledge transfer and self-efficacy promotion. This choice was made in order to put together the individual genetic risk, as derived by DTC-GT, with lifestyle factors (physical activity, diet, and social interaction) in order to better understand the role of genetics and environmental factors in the person's risk to develop a disease or to inherit a trait or condition. With the Adventure Game: "Gene Adventure" people can experience, through a simulated life, the management of complex information such as genetic risk information and move from basic genetic knowledge to some level of experience.

We have created an accessible and simple instrument, using a pleasant representation of genetic concepts and an appealing narrative, which respects the skills of the general public. We were able to demonstrate, at least from the observation of preliminary results, that the use of the Games for Learning developed increases people's knowledge about genetic mechanisms (heredity and mutation) and about how multiple genetic, behavioural and environmental factors together contribute to the risk of complex diseases onset, such as heart disease. We developed a logging system able to keep track of all the choices made by the player during the game, to further evaluate their decision-making processes and possible changes in behaviour.

The high compliance of the games suite developed, described here, shows that SG can be indeed a very good mean to educate people to correctly take DCT-GT and to make informed choices about own health management.

## 10.1 About Playability test results

A thorough evaluation of the usability of HerediRabbit, MutanTetris and Gene Adventure was performed, to identify design and functionality issues along with potential usability problems. In addition, we assessed players' personal experience with the game sessions to obtain feedback about the level of participation, amusement and perceived flow. Preliminary usability studies has allowed us to identify critical areas and refine the final versions of the games for the knowledge transfer and self-efficacy experimentation.

## 10.2 About Knowledge Transfer and Self Efficacy results

Remembering that the knowledge transfer and self efficacy tests were carried out on a small sample of twenty participants, it is necessary to consider the results obtained as preliminary. The conclusions in those respects are a little weaker as we cannot jump to conclusions although they do seem promising.

We evaluated the developed SG effectiveness in terms of learning outcomes in the field of genetics and genetic risk. Specifically, we:

- assessed the learning impact of the suite of mini-games developed on participant's knowledge and understanding of basic genetic concepts;

- assessed the effect of the adventure game developed on participant's skills and perceived self-efficacy concerning genetic risk management.

One aspect that we consider to be interesting is related to the increase in self-efficacy measured during the test performed. All the twenty peoples, no one excluded, after playing the games think they have substantially increased their self-efficacy on genetic issues. This, as mentioned in chapter 3.3.2, can be a valuable ally both in making better decisions in this area and in being more motivated in case more complex issues need to be investigated.

## 10.3 General comments

We propose a set of possible approaches to address knowledge transfer through SG using metaphors to highlight and present genetic concepts, customizing famous arcade games and using a dramatic curve narrative to balance the serious content and the entertainment part. The use of Arcade games to represent genetic concepts has been tested: the integration of educational content provides pleasure and longer game-play by leveraging the mechanics already experienced by millions of players.

Players were generally very happy about using Games for Learning. This seems to be a good and motivating solution to make people really informed about genetic tests and to increase the general public's understanding of the scientific, ethical, legal, and social issues related to public health genetics.

Most of the players, both during the playtesting experiments and during the subsequent experiments of knowledge transfer and self-efficacy, were shown to appreciate the games a lot, considering them funny and very instructive. Moreover, several times, at the end of the game sessions, the players freely started discussions with us trying to deepen their knowledge of genetic issues and sometimes making interesting points about DTC genetic tests.

## 10.4 What's next - Limits and future proposal

Even if these preliminary results do seem promising, the author understands that this is a first step in a longer process to produce serious games that can be demonstrated to achieve their goals. The process of producing the work described in the thesis has been very educational. The author now understands how difficult it is to actually produce games that teach people complex subjects. Lessons learned in the process will be applied to future projects and to also improve the games developed during this project.

The present study is designed to test "learning" meant as information acquisition: indeed, the pre-test and the post-test questionnaires measure performance by assessing correctly answered questions based on the new information acquired through the SG. As a further step, we will test another aspect of learning: the ability to apply the newly acquired

knowledge in unknown situations (e.g. creating a new scenario in which participants will be asked to make decisions involving their own health and based on genetic (risk) issues).

There are other interesting and related themes this research is not designed to investigate, e.g. knowledge integration (the ability to integrate into a coherent mental representation the information on a given subject deriving from different perspectives). At this very moment, our experimental protocol is not fine-grained enough to differentiate the contribution of each serious game in creating the final mental representation of genetic concepts. Analysis of the stored log files of the played matches, may present some valuable evidence about which concepts participants have engaged with.

Because of their efficacy, another important aspect that might be possible to explore is to use the developed SG in combination with other traditional protocols for genetic counselling, to facilitate awareness during decision-making paths in medical genetics.

APPENDIX $\mathcal{A}$

# Genetic Glossary

- ***DNA***: "Deoxyribonucleic acid, a self-replicating material which is present in nearly all living organisms as the main constituent of chromosomes. It is the carrier of genetic information.
  Each molecule of DNA consists of two strands coiled round each other to form a double helix, a structure like a spiral ladder. Each rung of the ladder consists of a pair of chemical groups called bases (of which there are four types: adenine, guanine, cytosine, thymine), which combine in specific pairs so that the sequence on one strand of the double helix is complementary to that on the other: it is the specific sequence of bases which constitutes the genetic information".

- ***Nucleotide***: "A compound consisting of a nucleotide linked to a phosphate group. Nucleotides form the basic structural unit of nucleic acids such as DNA."

- ***Genes***: "Genes are best known as the instructions for building proteins. However, only a portion of the nucleotides in a gene actually code for the protein itself. Other parts of the gene provide additional information—including sequences that control when, where,

and how much protein to make."

- ***Chromosome***: "Each chromosome consists of a DNA double helix bearing a linear sequence of genes, coiled and recoiled around aggregated proteins (histones). Their number varies from species to species: humans have 22 pairs plus the two sex chromosomes (two X chromosomes in females, one X and one Y in males)."
- ***Karyotype***: "A karyotype is an organized profile of a person's chromosomes. Two chromosomes specify sex, XX for female and XY for male. The rest are arranged in pairs, numbered 1 through 22, from largest to smallest."
- ***Genotype***: "The genetic constitution of an individual organism."
- ***Phenotype***: "The set of observable characteristics of an individual resulting from the interaction of its genotype with the environment."
- ***Sequencing***: "The order in which amino-acid or nucleotide residues are arranged in a protein, DNA, etc."
- ***Protein***: "Any of a class of nitrogenous organic compounds which have large molecules composed of one or more long chains of amino acids and are an essential part of all living organisms, especially as structural components of body tissues such as muscle, hair, etc., and as enzymes and antibodies."
- ***Trait***: "A genetically determined characteristic."
- ***Dominant***: "Relating to or denoting heritable characteristics which are controlled by genes that are expressed in offspring even when inherited from only one parent."
- ***Recessive***: "Relating to or denoting heritable characteristics controlled by genes which are expressed in offspring only when inherited from both parents."
- ***Co-dominant*** "occurs when the contributions of both alleles are visible in the phenotype."
- ***Heredity***: "The passing on of physical or mental characteristics genetically from one generation to another."

- ***Genetic risk*** : "Inherited risk factors are passed down from parent to child by way of genes. All humans have the same genes, but different people have slightly different versions of these genes"
- ***Allele***: "Each of two or more alternative forms of a gene that arise by mutation and are found at the same place on a chromosome."
- ***Homozygote***: "An individual having two identical alleles of a particular gene or genes and so breeding true for the corresponding characteristic."
- ***Heterozygote***: "An individual having two different alleles of a particular gene or genes, and so giving rise to varying offspring."
- ***Mutation***: "The changing of the structure of a gene, resulting in a variant form that may be transmitted to subsequent generations, caused by the alteration of single base units in DNA, or the deletion, insertion, or rearrangement of larger sections of genes or chromosomes."
- ***Evolution***: "The process by which different kinds of living organism are believed to have developed from earlier forms during the history of the earth."

## A.1 Abbreviations:

- GT: Genetic test
- DTC GT: Direct to consumer genetic test
- SG: Serious games

APPENDIX *B*

# Knowledge transfer Questionnaire pre and post

Below are the English and Italian versions, of the questions administered to the subjects before and after the execution of the experiment. No time constraint was given for the compilation of the test. The test consists of a total of 19 questions divided as follows: 9 multiple-choice questions and one open-ended question on heredity and mutation. 9 questions (true/false) taken from the test performed by Carere et al. [126] used to measure the knowledge of the general public about genetics.

**English Version:**

1. A gene is:
    A. an hereditary character
    B. the result of fertilisation
    C. the part of the chromosome describing a hereditary character
    D. the result of the hybridization
    E. a protein
2. The alleles are:
    A. inherited from a single parent
    B. different variants of the same gene
    C. the external aspects of an individual
    D. the set of characters observable in an individual
    E. changes in DNA sequences
3. What are the characters that do not jump generations?
    A. those dominant
    B. recessive ones
    C. maternal ones
    D. paternal ones
    E. hereditary ones
4. From a pair of rabbits with genotype Cc and cc what is the proportion of the possible genotypes of the children: (C = dominant character - c = recessive character)
    A. three rabbits CC and one Cc
    B. three Cc and one CC rabbits
    C. two Cc rabbits and two cc rabbits
    D. Four cc rabbits
    E. two rabbits CC and two rabbits cc

5. From two brown rabbits with genotype Cc in what proportion will be the hair colour of the children: (C= dominant character, brown colour; c= recessive character white colour)
    A. three brown rabbits and one white rabbit
    B. four brown rabbits
    C. two brown rabbits and two white rabbits
    D. three white rabbits and one brown
    E. four white rabbits
6. Which of these statements is false:
    A. Every mutation in a cell is inherited from the daughter cells
    B. Some mutations can be corrected by our body
    C. Some mutations can cause the development of a disease
    D. Mutations occur more frequently with aging
    E. All mutations can cause the development of a disease
7. The external agents that can damage the DNA are called:
    A. mutagenic
    B. mutants
    C. viral
    D. oncological
    E. DNA critical
8. What is germinal mutation? A mutation...
    A. in one of the cells which will give rise to the sperm or eggs (gametes)
    B. which occurs in the zygote
    C. which occurs in the embryo
    D. which cannot be passed on to the offspring
    E. occurred in a somatic cell
9. The mutation is:

A. the succession of changes that accompany the growth of an individual

B. a stable and heritable change in the genetic material

C. a particular type of metamorphosis

D. a specific type of cell division

E. the succession of changes occurring in the development of the embryo

10. Do the mutations that occur in our DNA all affect our health? Try to argue...

11. Healthy parents can have a child with an inherited disease.

    A. TRUE

    B. FALSE

12. If your close relatives have diabetes or heart problems, you may also be at risk of developing these conditions.

    A. TRUE

    B. FALSE

13. Some genetic diseases occur more frequently in particular ethnic groups.

    A. TRUE

    B. FALSE

14. Most genetic diseases are caused by a single gene.

    A. TRUE

    B. FALSE

15. When a genetic marker related to a disease is identified in a person, the disease can usually be avoided or cured.

    A. TRUE

    B. FALSE

16. A disease is only genetically determined if more than one member of the family suffers from it.

A. TRUE

B. FALSE

17. Some genetic diseases appear later, during adult life.

    A. TRUE

    B. FALSE

18. A healthy lifestyle can prevent or reduce the negative consequences of a genetic predisposition to a disease.

    A. TRUE

    B. FALSE

19. The environment has little or no effect on how genes contribute to a disease.

    A. TRUE

    B. FALSE

**Italian Version:**

1. Un gene è:

    A. un carattere ereditario

    B. il risultato della fecondazione

    C. la parte di cromosoma che descrive un carattere ereditario

    D. il risultato della ibridazione

    E. una proteina

2. Gli alleli sono:

    A. ereditati da un solo genitore

    B. varianti diverse dello stesso gene

    C. gli aspetti esterni di un individuo

    D. l'insieme dei caratteri osservabili in un individuo

    E. cambiamenti nelle sequenze di DNA

3. Quali sono i caratteri che non saltano generazioni?

A. quelli dominanti

B. quelli recessivi

C. quelli materni

D. quelli paterni

E. quelli ereditari

4. Da una coppia di conigli con genotipo Cc e cc qual è la proporzione dei possibili genotipi dei figli: (C=carattere dominante - c= carattere recessivo)

   A. tre conigli CC ed uno Cc

   B. tre conigli Cc ed uno CC

   C. due conigli Cc e due cc

   D. quattro conigli cc

   E. due conigli CC e due conigli cc

5. Da due conigli marroni con genotipo Cc in che proporzione sarà il colore del pelo dei figli: (C= carattere dominante ,colore marrone; c= carattere recessivo colore bianco)

   A. tre conigli marroni e uno bianco

   B. quattro conigli marroni

   C. due conigli marroni e due bianchi

   D. tre conigli bianchi e un marrone

   E. quattro conigli bianchi

6. Quali tra queste affermazioni è falsa?

   A. Ogni mutazione avvenuta in una cellula, viene ereditata dalle cellule figlie

   B. Alcune mutazioni possono essere corrette dal nostro organismo

   C. Alcune mutazioni possono provocare lo sviluppo di una malattia

   D. Le mutazioni avvengono con più frequenza con l'invecchiamento

E. Tutte le mutazioni possono provocare lo sviluppo di una malattia

7. Gli agenti esterni che possono danneggiare il DNA sono detti:
   A. mutageni
   B. mutanti
   C. virali
   D. oncologici
   E. DNA critici
8. Che cosa si intende per mutazione germinale? Una mutazione...
   A. in una delle cellule che daranno origine agli spermatozoi o ovuli (gameti)
   B. che avviene nello zigote
   C. che avviene nell'embrione
   D. che non può venire trasmessa alla prole
   E. avvenuta in una cellula somatica
9. La mutazione è:
   A. la successione di cambiamenti che accompagnano la crescita di un individuo
   B. un cambiamento stabile ed ereditabile del materiale genetico
   C. un particolare tipo di metamorfosi
   D. un tipo specifico di divisione cellulare
   E. la successione di cambiamenti che avvengono nello sviluppo dell'embrione
10. Le mutazioni che avvengono nel nostro DNA incidono tutte sulla nostra salute? Prova ad argomentare...
11. Genitori sani possono avere un figlio con una malattia ereditata.
    A. VERO
    B. FALSO

12. Se i tuoi parenti stretti hanno diabete o problemi cardiaci, probabilmente anche tu rischi di sviluppare queste condizioni.

    A. VERO

    B. FALSO

13. Alcune malattie genetiche compaiono più frequentemente in particolari gruppi etnici.

    A. VERO

    B. FALSO

14. La maggior parte delle malattie genetiche è causata da un singolo gene.

    A. VERO

    B. FALSO

15. Quando un marker genetico relativo ad una malattia è identificato in una persona, la malattia può solitamente essere evitata o curata.

    A. VERO

    B. FALSO

16. Una malattia è geneticamente determinata solo se più di un membro della famiglia ne è affetto.

    A. VERO

    B. FALSO

17. Alcune malattie genetiche compaiono successivamente, durante la vita adulta.

    A. VERO

    B. FALSO

18. Uno stile di vita sano può prevenire o ridurre le conseguenze negative di una predisposizione genetica ad una malattia.

    A. VERO

    B. FALSO

19. L'ambiente ha un effetto nullo o minimo su come i geni contribuiscono ad una malattia.

    A. VERO

    B. FALSO

APPENDIX C

# Self-Efficacy Questionnaire pre and post

Below are the English and Italian versions of the questions administered to the subjects before and after the execution of the experiment. There is no time constraint for the compilation of the test. The test consists of a total of 8 questions divided as follows: 6 questions about your perception of how much you are confident about some genetic issues. Two questions related to your perception of how well you answered the first part of the knowledge transfer tests in the genetic field.

## English Version:

1. I feel confident in my ability to understand topics related to genetics:
    A. Fully agree
    B. I agree
    C. I am uncertain
    D. I disagree
    E. Fully disagree
2. I can understand information about how genes can affect my health:
    A. Fully agree
    B. I agree
    C. I am uncertain
    D. I disagree
    E. Fully disagree
3. I have a precise idea of how genetics influences the risk of developing pathologies:
    A. Fully agree
    B. I agree
    C. I am uncertain
    D. I disagree
    E. Fully disagree
4. I have a precise idea of how my genetic make-up can affect the risk of developing a pathology:
    A. Fully agree
    B. I agree
    C. I am uncertain
    D. I disagree
    E. Fully disagree

5. I can explain to others how genes can affect a person's health:
    A. Fully agree
    B. I agree
    C. I am uncertain
    D. I disagree
    E. Fully disagree

6. I have a precise idea of how my lifestyle can interact with my genetic make-up in influencing my health:
    A. Fully agree
    B. I agree
    C. I am uncertain
    D. I disagree
    E. Fully disagree

7. With respect to the 10 questions you answered a moment ago about genetic knowledge, how many of them do you think you answered correctly? (indicate the number)

8. Referring to the number indicated in the previous question, how confident do you feel, in percentage, that you have answered those questions correctly? (indicate the percentage)

**Italian Version:**

1. Mi sento sicuro della mia capacità di comprensione di argomenti relativi alla genetica:
    A. Pienamente d'accordo
    B. D'accordo
    C. Sono incerto
    D. In disaccordo
    E. Fortemente in disaccordo

2. Sono in grado di comprendere informazioni su come i geni possano influenzare la mia salute:
    A. Pienamente d'accordo
    B. D'accordo
    C. Sono incerto
    D. In disaccordo
    E. Fortemente in disaccordo
3. Ho un'idea precisa di come la genetica influenzi il rischio di sviluppare delle patologie:
    A. Pienamente d'accordo
    B. D'accordo
    C. Sono incerto
    D. In disaccordo
    E. Fortemente in disaccordo
4. Ho un'idea precisa di come il mio corredo genetico possa incidere sul rischio di sviluppare una patologia:
    A. Pienamente d'accordo
    B. D'accordo
    C. Sono incerto
    D. In disaccordo
    E. Fortemente in disaccordo
5. Sono in grado di spiegare ad altri come i geni possano incidere sulla salute di una persona:
    A. Pienamente d'accordo
    B. D'accordo
    C. Sono incerto
    D. In disaccordo
    E. Fortemente in disaccordo

6. Ho un'idea precisa di come il mio stile di vita possa interagire con il mio corredo genetico nell'influenzare la mia salute:
    A. Pienamente d'accordo
    B. D'accordo
    C. Sono incerto
    D. In disaccordo
    E. Fortemente in disaccordo
7. Rispetto alle 10 domande di conoscenza della genetica a cui hai risposto poco fa, a quante pensi di aver risposto correttamente? (indicare il numero)
8. Rispetto al numero indicato nella domanda precedente, quanto ti senti sicuro, in percentuale, di aver risposto correttamente a quelle domande? (indicare la percentuale)

APPENDIX D

# Game Experience Questionnaire subset for media comparison

To carry out the media comparison test, we chose to use only a part of the questions that make up the game experience questionnaire [114]. Only those questions were chosen that made sense both for the control group that reads the flyer and for the experimental group that played the three video games proposed.

The participants were asked how they felt during the experiment.

Below are the questions to which the participants have responded by entering a value between 0 and 4 of the following Likert scale:

0. Not at all
1. Slightly
2. Moderately
3. Fairly
4. Extremely

## Appendix D. Game Experience Questionnaire subset for media comparison

**Table D.1:** *The subset of used question taken from the Game Experience Questionnaire.*

| Questions | 0:Not at all | 1:Slightly | 2:Moderately | 3:Fairly | 4:Extremely |
|---|---|---|---|---|---|
| I thought it was fun | ☐ | ☐ | ☐ | ☐ | ☐ |
| I was fully occupied with the game/leaflet | ☐ | ☐ | ☐ | ☐ | ☐ |
| It gave me a bad mood | ☐ | ☐ | ☐ | ☐ | ☐ |
| I found it tiresome | ☐ | ☐ | ☐ | ☐ | ☐ |
| I forgot everything around me | ☐ | ☐ | ☐ | ☐ | ☐ |
| I felt bored | ☐ | ☐ | ☐ | ☐ | ☐ |
| I enjoyed it | ☐ | ☐ | ☐ | ☐ | ☐ |
| I felt annoyed | ☐ | ☐ | ☐ | ☐ | ☐ |
| I lost track of time | ☐ | ☐ | ☐ | ☐ | ☐ |
| I was deeply concentrated in the game/leaflet | ☐ | ☐ | ☐ | ☐ | ☐ |
| I lost connection with the outside world | ☐ | ☐ | ☐ | ☐ | ☐ |

**Table D.2:** *Il sottoinsieme di domande prese dal Game Experience Questionnaire.*

| Questions | 0:Per niente | 1:Leggermente | 2:Moderatamente | 3:Molto | 4:Tantissimo |
|---|---|---|---|---|---|
| Ho pensato che fosse divertente | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ero completamente preso/a dal gioco/volantino | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mi ha messo di cattivo umore | ☐ | ☐ | ☐ | ☐ | ☐ |
| L'ho trovato stancante | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ho dimenticato tutto ciò che mi circondava | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ero annoiato/a | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mi è piaciuto | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mi sentivo irritato/a | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ho perso la cognizione del tempo | ☐ | ☐ | ☐ | ☐ | ☐ |
| Ero altamente concentrato/a giocando/ leggendo il volantino | ☐ | ☐ | ☐ | ☐ | ☐ |
| Mi sono scollegato/a dal mondo esterno | ☐ | ☐ | ☐ | ☐ | ☐ |

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