ExergyX as an Educational Game

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ABSTRACT

ExergyX is an energy management game, composed by a serious game model, which calculates emissions, efficiency ratio, aggregated efficiency and many others, based on the player's investment in renewable power. The main purpose of this game is to enrich students' experience in the learning of new concepts, such as understand the relation between energy and economic growth, realize what exergetic efficiency depends on and how it is possible to increase it, understand the paths for the carbon neutrality of the economy, and understand the difficulties/limitations of renewable electricity.

In this document, we explain our objectives of integrating the game in an IST course as well as on a MOOC. We provide an explanation of the background of the project, analysing the previous version of the game. Afterwards, we describe in detail the development process of the new version, which includes a renovation on the user interface, improvement of user interaction with the game and additions to the game model.

Next, we describe a user testing process with 24 participants, where each one had to fill a user experience questionnaire (UEQ), a system usability scale (SUS) questionnaire, and three open answers, providing their opinion about the game. We then analyse their answers for each one of the three components, conducting an adequate analysis for each of them, rating the application in two different aspects: user experience and system usability.

Finally, we conclude our work, identifying what is left to be done in future work. We believe that after finalizing these topics, we are able of conducting an experiment in a real life scenario, integrating the game with the IST course, measuring its impact on the learning process.

KEYWORDS

Game-based learning, educational games, educational technology, energy management.

1. Introduction

In this chapter, we explain the context and the goals of this project, explaining the research methodology behind it.

1.1. Context

Through the years, the game industry has been rising a lot due to the technological evolution, which attracted more and more people, substantially those in younger ages. We believe kids have a facilitated access to games nowadays in comparison with ten years ago. They take part in the routine of many people, some as an entertainment activity, others as a way of socialization and connecting with others, and some people even rely on games as their professional way of earning money. This huge development is so real that a new sports segmentation surged in order to fulfil the demand, the so-called E-Sports.

However, if we observe institutions in the scope of higher education level, despite the technological progress experienced, we believe the educational methodologies did not change a lot. Some infrastructures evolved, providing a better learning experience, quality and comfort, but the teaching methods do not reflect this huge development.

That is when *ExergyX* emerged as a means to change the current and traditional learning system. It is an energy management game, where students are challenged to embrace the role of a government advisor, with the responsibility of investing money on the country's energy development. It surged as a thesis project where, during that time, they developed a very real and serious model, composed by complex equations, aiming to reproduce a reliable simulation environment [1].

1.2. Objectives

In this dissertation, as a main goal, we propose a significant improvement to *ExergyX*. As we described before, the game has a very complex, serious and reliable simulation model, however, after analyzing the previous version of the game, it was notorious the need for improvement in the user interface implemented on the game. Therefore, we propose a significant enhancement on the game frontend layer, changing it completely, hopping to provide an engaging user experience. Additionally, aim to improve the game's playability by adding variety and new dynamics to it.

We also propose an improvement on the game model, adjusting or adding components to fit our needs and what we believe is best for a better gameplay experience.

1.3. Research Methodology

In order to achieve our goals, we had to plan our time and define a timing for each step.

Our planning was divided in four phases:

Analysis phase: In this step, we performed an exhaustive analysis on the previous version of ExergyX, where we identified the problems needing improvements. In this step, we also took in consideration the feedback received from specialists, where they pointed out some ideas and suggestions for the game.

Discussion phase: Afterwards, we got together to discuss what we collected from the previously mentioned analysis. Then through some weeks, we talked about our ideas to improve the game, never forgetting the suggestions, but also measuring what could be done in the available time. When we came to a conclusion, we started to define our priorities regarding the implementation of those changes.

Development phase: This was the longest and laborious step. Since we started the user interface from scratch, we had a lot of work to do and had to readjust throughout the implementation of the new features. During this process, we had some periods to discuss the state of our work and align on new possible features, analysing if there was enough time to deliver them.

Testing phase: Once we completed the development phase, we conducted a testing experience. This step was crucial to support our work, since until that moment the only critical analysis had been done by ourselves. We also considered very important to understand what is needed for future work and what was not so successfully implemented, in order to provide a great version of the product to students, when using the game as a learning tool.

Second Analysis phase: Finally, we once again conducted an analysis phase, where we went through the feedback resultant from the testing phase. We were able to evaluate our work regarding user experience and system usability. With the obtained feedback, we were able to define what is left opened for future work.

2. Related Work

In this section, we present some work related to the project that we considered in the analysis and development phase. Some of them were introduced in courses at universities and so, they represent an example regarding serious games and reliable game models, and others are inserted in the same subject as *ExergyX*, which is management games. Since one of our goals is to enhance the user interface of the game, it is also important to have this topic in mind when analysing and studying other games, so that we can compare and draw conclusions from that analysis.

2.1. IST Management Challenge

In 1980, SDG – Simuladores e Modelos de Gestão in collaboration with EXPRESSO journal, founded the Global Management Challenge (GMC), a strategy and management competition, involving both the business and university environments [4].

It is currently present in more than 30 countries and has engaged over 650 thousand participants worldwide since its first edition. Later, in collaboration with Instituto Superior Técnico (IST), they founded IST Management Challenge (ISTMC). Which is a strategy and management competition integrated in Management subject which integrates some courses at IST.

Each team, between 3 to 5 elements, assumes the role of a company's board of directors during the next 5 quarters. For that, the group has to analyse the recent past of the company, outline a medium-term strategy, make high responsibility decisions within various areas of the company and analyse the results obtained, taking into account the competition and the economic situation of the market.

This competition aims to increase strategy skills and management, teamwork and detect students with higher potential to be the best managers and future CEOs.

From our analysis, we conclude that this game is an excellent example of a serious game. The model behind is reliable and very accurate, simulating real word scenarios also in the scope of management. However, its UI is very poor, since students only have to fill an excel sheet and submit. We believe students would feel even more engaged if the UI would be somehow improved.

2.2. SimCity

SimCity, similarly to Cities: Skylines, it is a city management game.

Vanessa Haddad, Assistant Professor and chair of Liberal Arts, General Studies at the State University of New York (SUNY) Erie in New York, United States, has used this game as a tool to teach an introductory sociology course.

She describes that students were able to make connections between very basic functional perspectives, thus making the game a good and semi-successful tool, considering a variety of technical problems when using the game, for example problems with firewall, licenses for usage and hardware requirements to run the game. [5]

In Germany, Heinrich Söbke of Bauhaus-Universität Weimar, delivers a technical infrastructure management course, and adopted SimCity4 as a tool to help students understand the many interdependencies in a complex system. He divided the students by groups, and then each group's screen was projected on the wall, so the whole class can observe the progress of each group. The Activity was divided in three different supervised sessions. The first one was intended to familiarize students with the game, then, in a second session, students played in a given scenario where the city zones were already laid out. Finally, in the last session, students were encouraged to develop their own scenarios from scratch.

The professor's opinion about the game's impact in students' education is that they come away with an understanding of infrastructure planning and the need to "react immediately to an imbalanced development". [5]

This is a very similar example to the Cities: Skyline. Although, this has a very detailed study that we analyzed for future work, when we introduce students to the game. Additionally, it is relevant to point out the outcomes of the previously described experience. Students felt more engaged with the course just by simply adding a new learning tool. In addition, we can observe a comparative analysis between the game model and the real world, encouraging the students to develop their critical thinking about it.

2.3. En-ROADS

En-ROADS, a climate change solutions simulator, developed by Climate Interactive[1], Ventana Systems[2], and MIT Sloan[3] is a

[1] Visit corporation website: *https://www.climateinteractive.org/*
[2] Visit corporation website: *https://www.ventanasystems.com/*
[3] Visit corporation website: https://mitsloan.mit.edu/sustainability-initiative/welcome

policy simulation model. Different from previous works already discussed, this one in particular has a very similar purpose to ExergyX.
In En-ROADS, the user has the opportunity to design their own scenarios to limit future global warming. Comparing to ExergyX, the user also has the opportunity to define a strategy with the goal of leading the country to a cleaner and more sustainable future, by investing in renewable power, electrification policies or economy distribution policies, accordingly to a previously stipulated budget. Accordingly to their information, En-ROADS has already been used by a wide range of people, including members of the U.S. Congress, HSBC bank, the Hewlett Foundation, local community groups, the UN Secretary-General's Office, university professors around the world, leading science educator Bill Nye, and many others. For our project, we consider very important to have a simulator with all this usage because for future work we certainly need to revise our model and proceed to any possible adjustments, and having a reliable simulation model like En-ROADS, represents a huge possibility for comparing information and obtained results.

2.4. Analysis

After our study on the state of art, when it comes to games being used as educational complements, we can observe that not only they serve their purpose as motivational factor, but also as a way of improving students' critical thinking. Some games inserted in the simulation scope sometimes fail to provide a real and trustworthy representation of the real world, and yet they can be used as a model for comparison, where students can state and notice the different between the game's representation and the one they learn.
It is important to notice that some games presented in this section were not developed with an education purpose, thus making them an interesting choice to deeply analyse which feature make them into good and useful tools for education.
In each of these games, we saw some guidelines for the game that we are developing, the *ExergyX*, such as design approaches, user interfaces capable of captivating the students' attention, and aspects that help to increase their motivation. Our challenge is to create a serious game, but still making it enjoyable and pleasant for the users.

3. Conceptual Solution

Having in consideration the purpose of *ExergyX*, which consists of becoming an educational game, we previously defined a set of imperative key points, which we would ideally achieve with the final product. Those key points are mostly related with the game's playing experience, and consist on improving the UI, so the game becomes more appealing to the users. Improve the interactivity, which mean the amount of interactions that the user can perform and, we would like to preserve the game model seriousness, which is crucial since it is an educational game, and finally we decided to impose limits on the user control, adding elements of surprise.
We defined a game design framework to help us guide on the game's development and perform a critical analysis through several steps of the implementation process.

3.1. DPE Framework

The DPE framework was created by Brian M. Winn, as an expansion of the MDA framework to address the needs of serious game design for learning. It was built in three distinct components, identified in the name of this framework, Design, Play and Experience. [6]
This framework describes the relation between the player and the designer. While the designer is who designs the game, the player is the one that actually plays it, which results in player's experience. In this approach, the authors established a connection between Experience and Design, to point both the influence of the goals on the original design and the iteration on the design once a prototype of the game is tested against the experience goals.
The extended version of this Framework tries to identify and describe the subcomponents of serious game designs, including the Learning, Storytelling, Gameplay, and user experience layers. For each layer, the model provides an analysis regarding the three main components of this framework. Then, a representation of technology appears at the bottom since the designer does not implement it but the design itself can be realized in the technology.

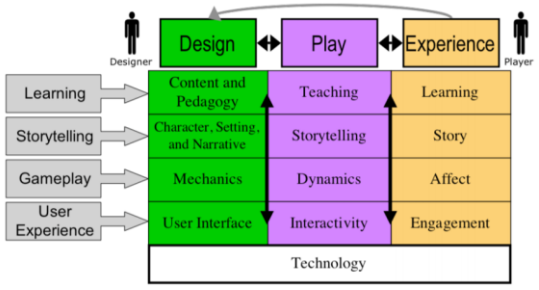

Figure 1 Extended DPE Framework

Winn replaces Aesthetics with Experience, acknowledging that the Aesthetics of a game are not directly received by the player, but experienced in an individual, subjective, and unique way. Each layer has influence over the other layers. For example, the learning will influence and be influenced by the storytelling, gameplay, and user experience.

3.2. Decision Analysis

Based on a previous study on game design frameworks, we decided that the one that best fits our project needs is the Design, Play and Experience (DPE) Framework. We think this is the appropriated one because it incorporates three main aspects that we consider relevant for *ExergyX*. The Design level defines the components of the game, at the level of data representation and algorithms. Having this aspect in mind is also important because, based on the information that we retrieved from the feedback analysis, the lack of elements of surprise, capable of captivate the user's attention to the game, and avoiding a boring and repetitive experience. The second part, Play, which includes the gameplay, was pointed as needing improvements. The biggest problem noticed was the lack of useful feedback to the user on what was happening during the simulation process, which can lead to a poor experience for him.

Lastly, we have the Experience level, which defines the user interaction with the game, and all the emotions flowing from the game to the player. This aspect was much criticized on one of our earliest analysis phase, because the UI integrating *ExergyX*'s first version was very poor and limited regarding user interactions with the game, leading to a very repetitive experience.

4. ExergyX: Alpha Version Analysis

In this section, we focus on analysing the previous UI, and some problems associated with it.

We will conduct a two steps analysis, first focusing on the user interface where we discuss mainly the aesthetics of the game. Then, we analyse the gameplay, aiming to identify some problems or enhancement opportunities that will provide a better experience for the player. Lastly, we present a description on the game model.

The first version of the game went live although it was not used in any course yet. It was only submitted to some user tests by specialists in the game's subject, and to a small group of students.

ExergyX was first implemented using GODOT[4], which is an engine design for game development. However, since we are not working with game elements such as light, shadow or textures, we decided to switch from this game engine to a web development technology, since the game is not a desktop application but a web application.

4.1. UI Analysis

Probably one of the first things that we notice when interacting with a game or an application, is the UI. The result from that experience can influence our opinion on it.

The first version of ExergyX had a poor interface, faulty and not so much user friendly. Some of their elements could cause confusion to the user or even lead them to misunderstanding the meaning of those elements because of the lack of guidelines through the playing experience.

First, we noticed the welcome screen, containing too much information, was not appealing to the user, and even leading them to skip it, probably without carefully reading it all. However, the information contained in there is really important and beneficial for the player, since it gives some hints on how to play the game. So we had to define a strategy where we could still provide this valuable information, but not in such a boring or distracting way. We discussed some options like and onboarding approach, where the information is divided through different steps, allowing the user to absorb useful tips and guides slowly. This way, the user can clearly understand it is a tutorial which he is able to skip at any time. We also considered implementing this component in a way that for each step of the tutorial, a certain element of the game is highlighted, helping the user to clearly relate explanation text with its element.

Another issue that we could find it is related with the main screen, which is where the user interacts and is provided with feedback on the changes after each submission. There we can observe the main content is not properly aligned and does not use the full screen width.

Ideally, the user should clearly understand which elements have additional information such as tooltips. On this first version, it is not clear where you should hover to see the tooltips and when it appears, it shows the hint text for a group of elements, making it hard to read the help text for a certain element. A better approach would be adding an info icon, which the user can easily associate with hint text, and, when hovered, shows information for its associated label. Additionally, the tooltip container should not have the same colors as the background elements, standing out from the other components.

When a submission occurs, the user sees a confirmation popup with the decisions' summary and then sees the main screen again. However, in this screen it is not clear which elements changed, he has no feedback on the decisions previously submitted. We discussed this topic and agreed on adding additional information to each label, representing the difference from the current and previous iterations. Simple adding this makes a huge difference when analyzing the information, helping to define strategies for the following decisions. Also, since the model is quite complex, we believe the game should give more information about what is happening.

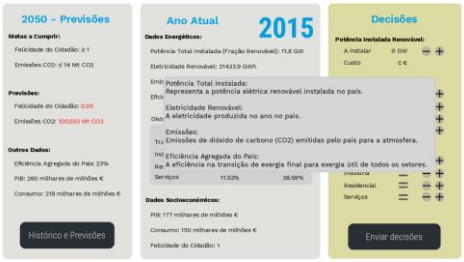

Figure 2 Old user interface

We also concluded the game lacks on the clarification of some icons and their meaning in the game context. In our opinion, the symbols could be improved or a brief explanation on its implication could be added. This is a crucial point because the game should be easily understandable for the students, and therefore it can lead to a misunderstanding on the game functionality.

4.2. Gameplay Analysis

The user is responsible for making decisions that will have impact in some socioeconomic and energetic areas, in the following year. The player's decisions must be done every year, starting from 2015 until 2050 and are related to the amount of renewable energy, in GW, to install, the investment to be done in different economic sectors, and the variation of the electrification by sector.

Since it is a simulation game, it is a challenge to find a context story for it, and therefore, depending on the game genre, the player experience lack on primary involvement. In the first stage of the development, the game introduces the player as a member of the

[4] https://godotengine.org/

government with detailed tasks and the respective objectives that he must fulfil.
Regarding the game scope, it is not clear that the user is focusing on electric energy emissions only, leading to a possible misunderstanding, since there are other scopes responsible for a great percentage of CO2 emissions. To be useful, the game must be accurate as possible for the player, when explaining the context and the scope where it belongs.
A general critic, made by different specialists, was that due to some lack of feedback about what is happening during each simulation, the games turns itself in trial and error, what is not very engaging. Since it is somewhat trivial to find a working combination, if the player repeats the same input every year of the simulation, it is certain that he will win. To avoid that and improve the game challenge, some variants could be added to the game, such as natural events or economic crises that would add a sort of restrictions and twists to the gameplay, forcing the player to change his current approach and to adapt his strategy to these variants.
Another important topic, approached by one of the specialists involved in the testing process, indicates it is expected that with more renewable energies there will be a closing of fossil fuel plants, which is invisible to the player. Although this information is present in the model, the difficulty is to understand how it can be shown to the player, without overloading him with information.
In this versions the player has to decide and simulate 35 times, which corresponds to the years between 2015 and 2050. Since there are no twists or unexpected events throughout the gameplay, makes it boring and a somehow unenjoyable for the players.

4.3. Model explanation

We think that a range of 35 years (2015-2050), since the start of the simulation until the evaluation of the previously defined goals, is a long period of time and it is not the most realistic one. If we have in consideration several aspects like the mandate's duration or how the performance of the current government influences the next election period, we understand that it is not realistic to only have goals after the referred time span.
Another topic is related to the economic concept in the game. In the first version, the user can see some information, indicating the total cost of the electrification process that he is simulating, and it is also possible to follow the decisions' impact on the gross domestic product (GDP), over the years. However, this parameter is almost irrelevant to take in account when making decisions because it is never evaluated and it is impossible to run out of money during the simulation, regardless the taken approach. Energy management and Economic management are two themes that should be related and connected, because investing in new sources of energy requires financial investment and this should be relevant too. Therefore, we believe it is necessary the implementation of a budget concept, where a portion of the GDP is made available for the user, who is responsible for managing it and invest accordingly to his strategy.
One thing that we received a lot of feedback was about the game model. It is complex and almost impossible to transmit all its information in the game itself. Therefore, to facilitate any adaptation on the game model, we decided to break it down into a diagram, so we can easily analyse possible changes and enhancements, and this way we are able to analyse all its relations and how user inputs affect the model and its calculations.

5. ExergyX: Beta Version Analysis

In this section, we will explain in detail our work in regard of taking *ExergyX* to the next level, improving its design, playability and implementation. At the end, we do a summary of which objectives were fulfilled and which were not. We decided to switch from GODOT to Angular [5]since GODOT is more suitable for games using textures, shadows, lightning, etc. On the other hand, Angular is better when it comes to data handling.

5.1. User Interface

As stated before, one of our major objectives was to make a user friendly and appealing UI.
We did an analysis on the previous UI, identifying some problems and enhancement opportunities, and defined some musts. One of the most relevant topic, also referred by some specialists, is the lack of feedback about what happens in the system. Analysing the old screen, we were able to observe that the information panel is small, providing so little information from a complex simulator.

Information Panel

In order to overcome this difficulty, we decided to split the main screen of the game in two different views, being the information panel one of them, where many details are available as well as the difference between decision years. This additional value facilitates the process of analysing the decisions' impact from the previous simulation, since it is clear how much a value changed after the submission. This panel is always available through the side navigation bar, where the user can easily switch back and forth between the different views.
Still in this panel, the user has access to a news box, where he is able to see some information about random events that occur from time to time. He can also see the impact associated with each one. This is an addition we made to the gameplay and it is described in more detail on the next subsection "Gameplay".
Additionally, we added tooltips to every label, making it easier for the user to clarify a specific topic. In comparison with the previous version, where the tooltip was not assigned individually but to a group of labels, making it harder to read and relate the description with the respective label.

[5] https://angular.io/

Figure 3 Information panel of the new UI

Decision Panel

The second view originated by splitting the main screen, is the decision panel. Here is where the player interacts with the game. This view is divided in three columns, where the first one contains a summary of the relevant information so the user does not have to always switch between views to analyse the data.

The second column contains the interaction elements, which are a policies table, containing investment policies, organized by sector, with which the user interacts by selecting them to see more details or adding/removing them to/from the shopping cart, and a certain amount of renewable power to install. This column also contains a card with the detailed information about any selected policy, such as title, sector, description, price and an image allusive to the sector.

Finally, on the third column, the user can see a summary of the investments he is making on the respective year, in real time. This information concerns the total amount of renewable power to be installed, the list of policies added to the cart, policies and renewable power costs and lastly, the remaining budget, which is also a new concept that was added and we explain it in the "Model" subsection.

Afterwards, when the user is ready to submit any decisions, he sees a confirmation popup, summarizing all the decisions that he is submitting, as well as a message reminding the player that once the submission is confirmed, he will not be able to undo this action. Then, after confirming everything, he has the option to submit and proceed to the next decision moment or to go back and change any decisions.

Figure 4 Decision panel of the new UI

History Panel

Once concluding a submission, the application redirects the player to the information panel, where the updated information is presented to him.

However, at any moment of the game duration, he is free to navigate to the history panel. In this page, the user can analyse and compare data from the past decisions years. Additionally, he has the opportunity of seeing the CO2 and population happiness progress through a line chart.

This view is divided in two columns, where the first one contains a line chart with the records for CO2 emissions and population happiness through the years until the moment he is at, which are the two goals to win the game. The player is able to filter the chart by showing or hiding lines, he can even observe the actual value at any available year. Still on the first column, there is a section, "Achievements", which is not implemented yet and we talk about it in the "conclusion" section of this document.

For the line charts, we used an open source library, available under the MIT license, called Chart.js. When used together with ng2-charts, which is another node.js library, we obtain good looking and dynamic charts. In our application, we only use line chart, but there are more options available.

On this same view, on the second column, the user is able to see the history so far by choosing one of the previous decision years. Once one option is selected, all the relevant information of the respective year is available for the player. This contains not only the value of parameters but also all the decisions made on that year.

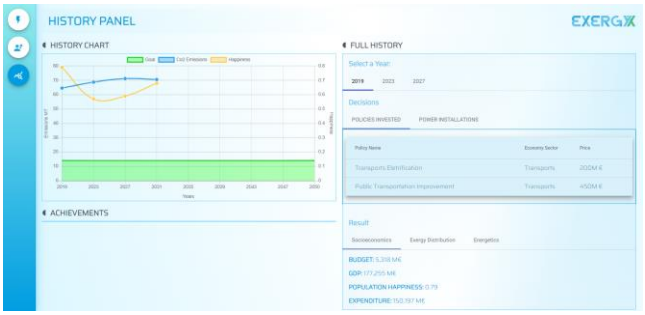

Figure 5 History panel of the new UI

Complementary Views

The three main views are described in detail above. However, we developed two more views to complement *ExergyX*.

The firs view that we added was a welcome screen, which is the first thing the user sees when accessing the website. Our intentions with this view were to create an appealing first impact instead of a page with great amount of information right away, which happens in the old version. Two elements, an inviting title and a "start system" button compose this view.

In addition, since the game is not trivial, we needed a good solution to provide some background information and some kind of tutorial. We already described some reasons why we believe the information screen on the old version is not suitable for this game.

All things considered, we implemented a sequential tutorial, where the user sees an image of the actual game with some elements highlighted, and a text explaining on how to use those elements in

order to achieve something. With this approach, the user is able to relate a small text portion with specific elements of the game.

5.2. Gameplay

After analyzing the previous version of the game, we concluded that the gameplay needed improvements. The interaction between the player and the environment was lacking on diversity and engagement.

Since the feedback that we received, from the testers of the previous version, contained a lot of statements on how boring the game could become for the player, as result of 35 simulation periods. To overcome this, we decided to change from every year to every four years, aiming to reduce the amount of decisions and also bring some reality to the model, because some of the decisions are infeasible in one year.

The first step was to define clear objectives that ideally every player would obtain from the playing experience. Some of those topics regard theoretical aspects, since this is an educational game, with the purpose of helping students understand and apply the course subject.

One of those news concepts, **politics**, is one of two ways used by players to invest in the game. Each politic has an economic sector associated with it, representing where it will have impact. Politics can represent an investment in electrification of the respective economic sector, which rises the sector's electrification percentage, or a modification on the sector's weight, which means the respective sector's share of used energy is reduced. Through these politics, we can guide the player to think about the current state of the country and decide which politic would suit best. We created politics that are viable in the real world but also makes sense in the context of the course where they are to be applied.

In the game model, we created a structure "Politic" containing all its properties, necessary to its integration in the already implemented model. Each politic is essentially composed by a title, simple captive text, a description, containing essential information such as what to expect from it, a type, identifying to which sector it belongs, a price, which will be withdrawn from the budget and an impact reflecting how much it will affect a certain parameter.

All the remaining properties we use for validations, sorting and management.

Another new concept that we added to the model were **natural events**. Since the previous version of the game was somehow predictable when a good combination was found, we researched and debated possible solutions for this problem.

For the purpose of overcoming this inconvenient, we implemented a new dynamic in the game model, which is not directly associated with user actions. The natural events, as we implemented it, occurs every other simulation year, and mainly contains negative events such as dry season or a tornado occurrence, which will affect hydropower or destroy renewable power capacity, respectively.

There are also some motivational news with no negative impact in the model. To avoid repetition, we imposed a limit of one occurrence per event. This information is available at any time in the "Information Panel", which can be accessed at any time. As it was previously said, there is no possible interaction by the user regarding this topic.

5.3. Summary

After the development phase, we believe that the previously defined objectives were fulfilled, with the exception of one.

Remake the user interface: we believe that the new interface has nothing to do with the previous one. We designed a new concept for the game, very distinct from the original, by taking in consideration all the feedback we received and all the inputs from outside. Also with the purpose of delivering a good looking and appealing game to the students who will play this game, hoping to increase their engagement with the course and also enrich their learning experience with a new tool.

Improve the interaction: This goal was achieved by adding politics to the game, which represents a new way of interacting with the game, emerging new feelings and experiences.

Enrich the gameplay: We believe the gameplay was greatly improved with the addition of politics and natural events. These elements bring more diversity to the gameplay, and also unexpected events, causing the player to constantly adapt his strategy.

Improve the model representation: With the implementation of an information panel, we believe we have achieved this goal, since the user has more information to see and analyse in a proper view, specially dedicated to this purpose.

Perform a testing experience: This objective was not fulfilled. We conducted a testing phase with a random set of users to support our work and identify possible problems. However, due to all the formalities and the development period, it was impossible to conciliate a testing phase since during our development phase the course was not being taught.

6. Evaluation

As we previously spoke, this project has already undergone a user testing phase where some problems were detected, regarding user experience. We then restructured the frontend layer, to address the problems detected and improve the gameplay experience.

We decided to conduct a user experience test, to evaluate the new user interface and to get feedback from participants about the new design and layout, and their experience while playing the game. Additionally, it would be very helpful if those same users could report new bugs, or even suggest improvements for the application.

6.1. Procedure

For this test, we gathered a group of people, most of them IT professionals, as volunteers for this testing process. However, there were a few requirements. Users must use a computer (either laptop or desktop) and internet connection is required since the game is deployed online, preferably using chrome as the internet browser. Finally, the user should complete a form, allowing us to collect detailed feedback.

First of all, the user has to read a consent form, containing a brief overview of the conducted study as well as all the ethic guarantees and data protection policies. After accepting the consent form, they

proceed to the study itself. As a first step of the study, users must access, via web browser, the site where the game is deployed, via the URL: "*exergyx.tecnico.ulisboa.pt*". Once in the webpage, they had to undergone and conclude the tutorial, as we also wanted to collect feedback about it. Afterwards, they were asked to finish the game at least one time (users were allowed to play more than one time). We used a "User Experience Questionnaire" (QUE) [7,8,9,10] to measure user experience and, to measure usability, we asked them to answer a "System Usability Scale" (SUS) [11,12] questionnaire.

Additionally, the form also contained three open answers, which were the following: "*Please describe any negative topic from your playing experience*", where they could right anything bad about the game, helping us to understand where we may have failed; "*Please describe any positive topic from your playing experience*", again, any positive topics would help us define and align our path; "*Please provide any suggestions for future improvements*", with this sort of suggestion box, our goal was identify some topics that not necessarily makes their experience bad, but maybe could improve their feelings while playing the game.

For this study, we add a total of 24 participations from people with different backgrounds and professional experience, which represents our sample for this experience. Every volunteer answered the three components of the form, and their responses were used in the following analysis.

6.2. Results: UEQ

We used a UEQ where both classical usability aspects (efficiency, perspicuity, dependability) and user experience aspects (originality, stimulation) are measured.

The questionnaire consists of 26 pairs of contrasting attributes that apply to our product. The user can express his agreement with the attributes by ticking the circle that most closely reflects his impression.

We obtained the following results:

UEQ Scales (Mean and Variance)		
Attractiveness	↑ 1.021	1.02
Perspicuity	→ 0.250	2.13
Efficiency	↑ 0.844	1.54
Dependability	→ 0.438	0.56
Stimulation	↑ 0.844	0.98
Novelty	↑ 0.875	1.16

Table 1 Results from UEQ responses

Values between -0.8 and 0.8 represent a more or less neutral evaluation of the corresponding scale, values > 0,8 represent a positive evaluation and values < -0,8 represent a negative evaluation. The range of the scales is between -3 (horribly bad) and +3 (extremely good). However, in real applications, in general, only values in a restricted range will be observed. It is due to the calculation of means over a range of different persons with different opinions and answer tendencies (for example the avoidance of extreme answer categories) extremely unlikely to observe values above +2 or below -2. Thus, even a quite good value of +1.5 for a scale looks from the purely visual standpoint on a scale range of -3 to +3 not as positive as it really is.

Afterwards, the above table is plotted into the following bar chart, providing a visual understanding of the obtained results.

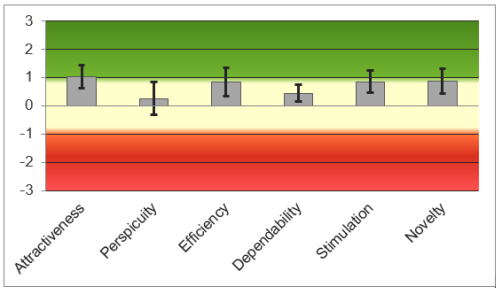

Figure 6 Mean and variation of UEQ responses

After analysing this data, we can now provide a conclusion for each scale and also determine what it is necessary to obtain better results. In general, it is motivating to understand that *ExergyX* did not get any negative mean score on any scale.

Regarding the **Attractiveness** scale, we got a score of 1.021, which represents the higher from every scale. We believe this is a very positive result since one of our main goals was to improve the user interface, providing a more attractive, user friendly and engaging application. However, we are aware that there is still some work to do, based on the feedback and suggestions we received. We can conclude that overall, users enjoyed our product and found it appealing.

The second scale, **Perspicuity**, is where we got the lowest score of 0.250. Despite being a neutral result, which ranges between -0.8 and 0.8, we believe that due to the complexity of the game, and it being inserted in a very specific scope, was a determinant for the result. We are also aware that the difficulty of winning the game could lead some user to frustration, influencing their decisions about this topic. Therefore, for future work, the game model should be reviewed in order to deliver a challenging, difficult but not impossible experience.

Regarding **Efficiency**, we obtained a result of 0.844, which is a positive score that once more demonstrates *ExergyX* is a well-integrated system, with a great potential. Again, we should understand what could be improved, and for that, the analysis of the suggestions provided is crucial.

Next comes the **Dependability** of the system, where we obtained a result of 0.438. Once again, it is a neutral evaluation, maybe reflecting the difficulty reported by some users, to identify the impact of their decisions in some parameters of the game. Since it is a complex model, it is not trivial to understand the direct impact of some actions because some values are a result of several operations on the background, with different variables and not only related with user inputs.

For the **Simulation** scale, we obtained a result of 0.844, showing that users found our game exciting to use. No doubt, that climate changes and the need of a cleaner future, are becoming a popular theme every day. We believe the users felt that the game's topic is very relevant for these days and interesting for someone not from this professional area, to simulate and try to discover a solution.

Finally, on the **Novelty** scale, we obtained a result of 0.875, which is the second higher value. In our opinion, the users felt that our game was different from other energy management games, and maybe addresses climate problems in a more serious way. For us it is a positive feedback, since our goal was not only develop an energy management game, but also teach the player with real world scenarios and a reliable simulation model.

6.3. Results: SUS

The second evaluation questionnaire was a System Usability Scale. It offers a quick and effective way to evaluate the usability of our product and design. This approach was developed by John Brooke to address the problem of evaluating a system usability. This questionnaire was composed by ten sentences, which the user should classify from "strongly disagree" to "strongly agree".

The SUS is generally used after the respondent has had an opportunity to use the system being evaluated, which in our case was *ExergyX*. To calculate the SUS score, we first gave each option a score from 1 to 5, being 1- strongly disagree and 5 – strongly agree. Then summed the score contributions from each item. Each item's score contribution will range from 0 to 4. For the odd items, the score contribution is the scale position minus 1. For the even items, the contribution is 5 minus the scale position. Multiply the sum of the scores by 2.5 to obtain the overall value of SU, which have a range of 0 to 100 that does not represent percentage.

We used an equivalent function for the calculation, where for the odd numbers we add up the total score for all odd-numbered questions, then subtract 5 from the total. And, for the even numbers, we add up the total score for all even-numbered questions, then subtract that total from 25.

For this calculation, we computed the means for each one of the 10 items, and then we proceed with the remaining calculation, obtaining the following table.

Item	Mean	Rounded Mean
1	2.96	3
2	2.33	2
3	3.63	4
4	2.21	2
5	3.83	4
6	2.25	2
7	3.71	4
8	1.50	2
9	3.54	4
10	2.17	2

Table 2 Calculated mean for each item of SUS questionnaire

Afterwards, we computed the values for the even and odd-numbered questions, identified as E(x) and O(x) respectively.

Function	Mean	Rounded Mean
O(x)	13.17	14
E(x)	15.50	15
SUM	28.67	29
SUS Score	**71.67**	**72.5**

Table 3 Additional calculation steps and final score

The next step is to find where, in the rating scale, our project is. For that, we will use a rating scale, containing rating elements such as, NPS, Acceptable, Adjective and Grade.

The **Net Promoter Score (NPS)** designates three classes of recommenders based on the results. They reflect the user's willingness to recommend the application, classifying it in Promoter – high chance of being promoted by the user, Passive – the user may or may not promote, or Detractor – the user will recommend to not use the application, which obviously is the worst-case scenario.

The **Acceptable** is one way of using words to classify the application. Generally, an overall score roughly below 50 will be classified as unacceptable, a score above 50 is labelled as marginally acceptable, and a score above 70 is classified as acceptable.

Regarding the **Adjective** classification, it is another example of word classification. Roughly below 50 is classified as poor, and below 25 as worst imaginable. Between 50 and 70's is classified as OK, between 71 and 80's as good. Between 81 and 84 is classified as excellent, and finally, above that is labelled as best Imaginable.

The table below provides an overview of these values, helping to visualize the differences.

After analysing this data, we can classify, based on users' opinions that our application is **good**, it is **acceptable,** it is **passive** when it comes to create the desire of promoting the system, and finally it receives a **C+** grade.

In our opinion, we believe that the downside of our game is the impossibility of reaching good results throughout the gameplay, leading the player to victory. We will discuss this is the next subsection, based on the open answers that we received.

6.4. Open Answers

In the third component of the user test, we asked the participants to answer three open questions. Our main goal is to understand any problems they had during the experience, analyse where we succeed and collect ideas and suggestions for future work improvements.

We were able to conclude that the participants overall enjoyed the game. Some more than others, as expected. However, from their perspective, we still have some work to do, mainly regarding the model itself, but we also need to fix some issues on the interface as well as on the model representation. We also believe that some issues that were raised are related to the subject where the game is inserted, which is strange and unknown to some participants. This condition partially influences their understanding on some topics and concepts. Nevertheless, the model will certainly be reviewed.

7. Conclusion

This dissertation proposes a new version of *ExergyX*, a serious energy management game. We believe the developed product is a short step away from becoming an educational game. We have strong convictions about the impact of integrating the game as a learning tool, representing an innovation in the learning system, potentiating students' motivation in the course. We carefully analysed the previous version, identifying which aspects of the game needed improvement. Afterwards, we defined a strategy to

overcome those limitations, aiming to deliver an enjoyable and useful tool for students. From the conducted study, we concluded that *ExergyX* is in the right path to achieve the desired goals, although there is still work to be done.

7.1. Contributions

To achieve the objectives of this research, the most important contributions of this dissertation can be summarized as follows: (i) Definition of clear objectives and concepts, which need to be represented in the game; (ii) Implementation of a new front-end layer of *ExergyX*, providing a more engaging experience to the players; (iii) Improvements on the gameplay, enhancing user interactions, and by adding clear and specific tooltips to each label; (iv) Improvements on model representation, providing more content and information about some parameters of the model; (v) Conducting a user experience test, which allowed us to collect information about the current state of the game, and to support the developed work.

7.2. Future work

For future work, we defined some topics, which we believe are essential before integrating ExergyX with both IST's course and MOOC.

The most important and critical issue, is to revise the game model, proceeding with any necessary adaptations, in order to improve the game's playability. In the current version, it is not possible to win by any means. We believe this happens because of the realism of the model.

Second, we shall carefully analyse the open answers to the questionnaire and proceed with any enhancements to the game. We already have some topics in mind, which need improvement, such as the tutorial, which was much criticised in the evaluation, but also the clarification on some concepts that are hard to relate throughout the game. Some of these topics are:

- Improvements on the tutorial, making it more clear and accessible for the players;
- Improve the cohesion of game concepts during the gameplay;
- Implementation of an achievements system, where the player is rewarded during the gameplay, as he achieves some milestones;
- Improve the accessibility, making the game compatible with more browsers, and responsive;
- Fix minor UI problems, identified during the testing phase.

Finally, we are considering another test, this time inserted in the IST course, with the enrolled students, as an experience to measure the impact of ExergyX as a learning tool. We believe the introduction of ExergyX in "Management of Energy Systems" course at Instituto Superior Técnico (IST) [2], which has an attendance of about 80 to 90 students, would represent an improvement on the current learning system at IST serving as a complement to the theoretical and practical classes where students could apply and test their previously acquired knowledge. We would like to provide a more attractive learning experience, potentially motivating more students.

Another way to measure ExergyX's impact would be the integration with the IST MOOC course "Energy, Economic and Environmental Scenarios" [3], which consists in an online course addressing similar topics and subjects as the IST course that we previously brought to discussion. We strongly believe that having an online learning tool is taking advantage of the technological progress, using it for the good of education, by providing new learning possibilities to students anywhere on the globe. Therefore, having an educational game as a complement would be a small but important step in innovating the learning system, as we know it today.

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