Enhanced virtual learning spaces using applied gaming

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Abstract. Online virtual labs, emulate real laboratories where students can accomplish a number of learning tasks and receive courses that otherwise would be difficult if not infeasible to be offered. In reaching this challenging goal, we developed two virtual labs enhancing students knowledge by providing an entertaining and engaging experience. Ensuring that the educational requirements of educators and students will not be overlooked, extensive evaluations of the virtual labs were deployed. Both virtual labs were accompanied with game analytics enabling detailed tracking of learner behavioral data. Tracking and understanding behavioral data facilitated decision-making at the design level of a lab, but also allowed for adapting learning content to the personal needs of the students.

1 Introduction

As computer technologies become an integral part of modern life, school administrators, teachers, and researchers strive to incorporate the technologies into classrooms to improve student learning outcomes [3]. The concept of immersive education has been applied to all aspects of education, including formal-institutional education, informal massive education, and professional training in companies [9]. One important type of such educational games are those for Science, Technology, Engineering, and Mathematics (STEM) education [10].

Virtual Laboratories are a useful and efficient educational tool for acquiring knowledge and enhancing learning. Video games with the advances of graphic hardware have fostered the creation of realistic virtual labs [4]. A rapid and drastic fall in prices, a huge leap in the computer processing power, the proliferation of World Wide Web and the prevalence of broadband connections have aggravated the use of desktop VR [6]. Augmented Reality and Mixed Reality are also attractive sections of the game industry offering immersive experiences. Serious games can exist in the form of mobile applications, simple web-based

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solutions, and combinations of social software applications or in the shape of "grown-up" computer games. Employing modern games technologies to create virtual worlds for interactive experiences may include socially based interactions, as well as mixed reality games that combine real and virtual interactions, all of which can be used in virtual labs applications. The main strengths of serious gaming applications may be generalized as being in the areas of communication, visual expression of information, collaboration mechanisms, interactivity and entertainment [1]. In our work, we exploit the recent advances of 3D gaming in order to improve the look and feel of two 2D labs namely one for Chemistry and one for Wind Energy, originally developed in the GoLabs project[5]. Our 3D and the old 2D labs can be played freely in our project web page[6].

The purpose of our work is to offer a solution towards optimizing the learning process in virtual labs and therefore maximize their impact in education. In reaching this challenging goal, we managed to migrate knowledge from the neighboring domain of digital games, where the capture and analysis of detailed, high-frequency behavioral data has reached mature levels in recent years. In digital games, Game Analytics (GA) is used to profile users, predict their behavior, provide insights into the design of games and adapt games to users. Tracking and understanding behavioral data can facilitate decision-making at the design level of a lab, but also can allow for adapting learning content to the personal needs and requirements of students.

The rest of the paper is organized as follows. Section 2 reviews related work. Section 3 provides the details of gamification and game design for the two case studies, namely the *Chemistry Lab*, and the *Wind Energy Lab*. In Section 4, the results of the conducted user evaluation for our Virtual labs are presented. Section 5 concludes our work and proposes future developments.

2 Background and related work

Several studies test the hypothesis that video games have a positive effect on supporting educational goals. These studies on the application of videogames in school curricula concentrate on the impact of the material in the game to learning goals [2]. In [5], the pedagological foundations of modern educational computer video games, that were developed between 2000 and 2007 strictly for educational purposes to facilitate achievement of specified learning objectives are studied. A ten-year critical review (1999-2009) of empirical research on the educational applications of VR was presented in [7]. Results show that although the majority of the 53 reviewed articles refer to science and mathematics, researchers from social sciences also seem to appreciate the educational value of VR and incorporate their learning goals in Educational Virtual Environments (EVEs).

In [9], a summary of the state of the art in virtual laboratories and virtual worlds in the fields of science, technology, and engineering can be found. The

[5] https://www.golabz.eu/

[6] http://www.envisage-h2020.eu/virtual-labs/

main research activity in these fields is discussed, but special emphasis is put on the field of robotics due to the maturity of this area within the virtual-education community. In most cases they are specific to an educational context, but do not offer possibilities for generalization to a platform applicable to a wider class of engineering disciplines. These laboratories have different levels of technical complexity. The most recent publications include the *Captivate* project [10]; a mobile game for STEM in higher education. In [8], a research study on the effectiveness of a new interactive educational 3D video game *Final Frontier* can be found. The game supports delivery of scientific knowledge on the Solar system to primary school students.

Relatively recently, Artificial Intelligence (AI) is also used to analyze games, and model players' profiles as game developers need to create games that appeal diverse audiences. Facebook games such as *FarmVille* were among the first to benefit from continuous data collection, AI-supported analysis of the data and semi-automatic adaptation of the game. Nowadays, games such as *Nevermind* can track the emotional changes of the player and adapt the game accordingly [12].

In our work, the cardinal objective is to optimize the design and functionality of virtual learning labs from the perspective of both the teacher (i.e., the designer of a lab) and the student (i.e., the user of a lab) by applying technologies developed in the gaming industry for authoring games, and for collecting game analytics encoding the activity of learners.

3 Methodology

In order to achieve a correct balance between entertainment and education, we collaborated with educators from *Ellinogermaniki Agogi* school[7], that helped us with the initial requirements of the games. Next, the Labs were designed and implemented using Unity3D game engine[8] and Blender design software[9]. The Labs are compiled for WebGL format in order to be easily accessible by the students. Moreover, Analytics tracking was also implemented inside the virtual labs for monitoring players' activities and modeling their learning behavior. Evaluations by questionnaires were filled in by the educators from *Ellinogermaniki Agogi* in two cycles providing valuable feedback. Pilots with students from the same school were conducted, collecting a broad amount of player's data, as well as feedback for improving the general design of the games. Lastly, we managed to equip virtual labs with tools that perform Dynamic Difficulty Adjustment (DDA) and semi-automatic adaptation of the learning parameters according to personal requirements of the learners. In the following an extensive description of the two Virtual Labs is presented.

[7] http://www.ea.gr/ea/index.asp?lag=en
[8] https://www.unity3d.com
[9] https://www.blender.org

3.1 Virtual labs development

The Chemistry Lab: The Chemistry Laboratory aims to educate students about the science of chemistry through an engaging and visually appealing experience. The general concept of the game has been designed to suit the needs of chemistry curriculum in primary and secondary schools. The game focuses on molecules names, formulas and 3D structures. During the development of the game, two pilots took place inside the classrooms of two schools. The initial pilot was performed from students and teachers of *Ellinogermaniki Agogi* school. Another pilot run took place in a Greek vocational training institute with a different audience (3D graphics students) that also suggested changes that helped making the game more appealing and entertaining.

The Lab immerses the player to feel like he or she is really working in a realistic chemistry lab environment. The main and first interactive scene of the game, is a 3D environment as shown in Figure 1. The look and feel of the lab environment has been designed based on real chemistry labs in order to immerse the player in the virtual world, but also display the rational appearance of a lab working environment. Discrete signs were placed inside the lab environment to inform the player about potential hazards and safety practices.

Regarding the main gameplay elements, the player learns about chemistry molecules through two mini-game quizzes. The first one is called molecule Naming and tests player's knowledge on molecules formulas and names. The second one, is called Molecule construction and gives the ability to the player to construct the 3D shape of a molecule from its given formula. The player can be

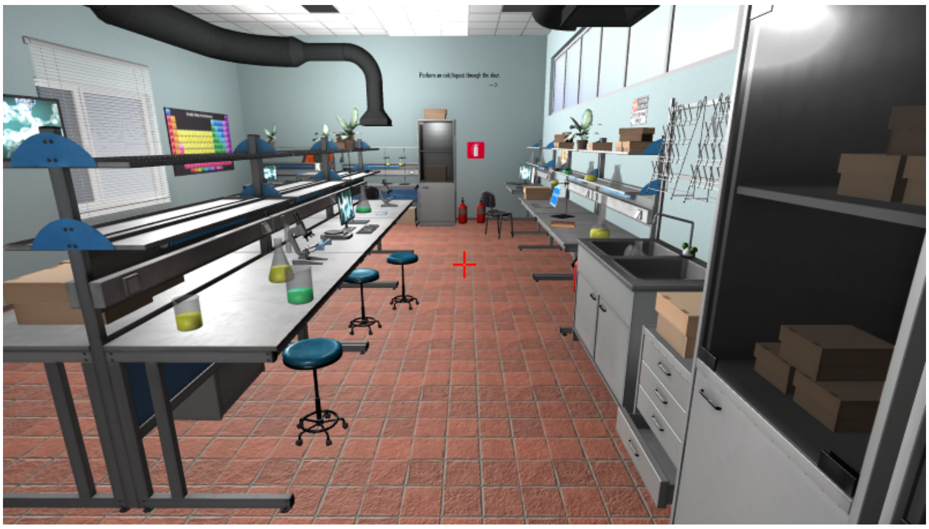

Fig. 1. The chemistry lab game environment.

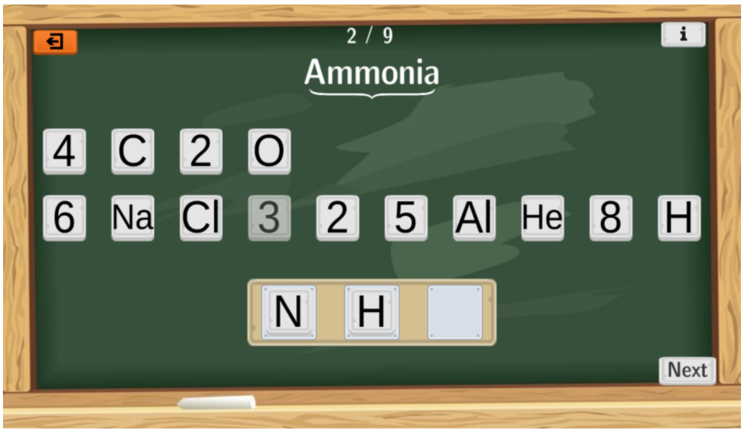

Fig. 2. The formula naming 2D mini-game.

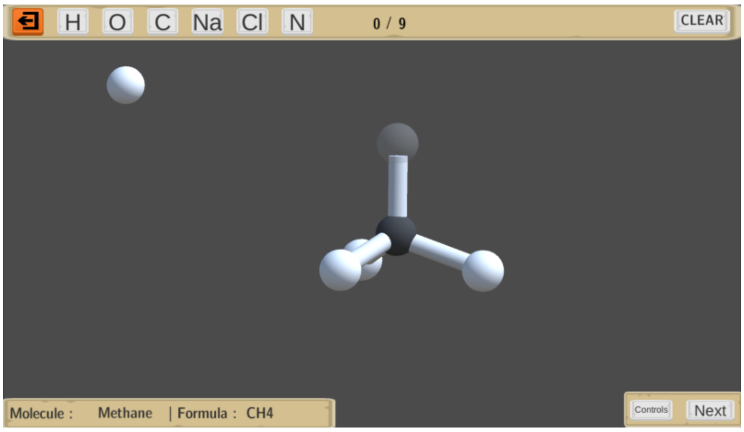

Fig. 3. The molecule construction 3D mini-game.

transferred in these mini-games by interacting with two different virtual laptops that can be found inside the lab environment.

More specifically, Molecule Naming as shown in Figure 2, is a 2D mini-game where the player is given a molecule name and must choose from a list of given atoms, the ones needed for assembling the molecular formula type and place them in the correct order. Molecule Construction mini-game on the other hand has a more complex interface where the player can create specific elements and try to place them in a 3D dimensional space in order to create the molecules 3D structure as shown in Figure 3. The learner can rotate the 3D molecule model and drag and drop elements onto the structure by moving them in different dimensions. A score is displayed that validates his overall performance during the two mini-games.

The Wind Energy Lab: In the Wind energy lab the player controls a wind farm in order to provide electrical energy to a small town. The player understands how random changes in wind speed and power requirements of the town affect the use of this natural energy resource. It has been integrated inside the educational curriculum of the *Ellinogermaniki Agogi* school, where two pilot runs were conducted from three different classes participating and providing feedback.

The lab has three phases namely a) the construction, b) the simulation, and c) the answering to some questions regarding strategic future decisions on the farm. Concerning the construction process, when the game starts a sheet is displayed to the learner that presents specific requirements and energy needs. Subsequently, based on the requirements, the learner must make a choice about the installation location of his wind energy farm. There are three available choices such as Mountains, Fields, or Seashore as shown in Figure 4, where each one has its own pros and cons regarding installation cost and wind speed. After the learner chooses a main region to install the wind farm, he/she is transferred to the 3D environment of the region in order to inspect the game terrain and choose a specific area in the region to install the park (Figure 5). However, each of these areas have different characteristics and risks. For example, some areas contain natural resources or archaeological places that induce a score penalty. In the final phase of the installation, the player can choose the type of wind turbine to use among different types having different efficiency and size.

In the second phase, the learner is transferred to the specified 3D simulation environment in order to control the wind farm (Figure 6). The goal is to produce a balance between the amount of energy produced with the one required. To achieve this, the learner can activate or deactivate some wind turbines. The wind speed is changing rapidly so as to force the learner to change his/her plans and make new actions. In the final phase, when the simulation ends, a multiple

Fig. 4. The main region selection scene.

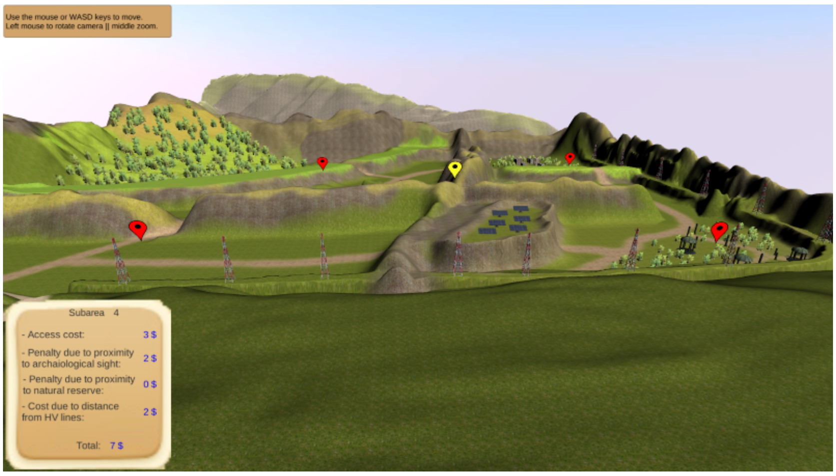

Fig. 5. The installation area selection stage.

Fig. 6. The simulation scene with the installed wind farm.

choice quiz is presented where the learner should answer questions related to future scenarios such as demographic changes in the area. In the end, a score tab is displayed that evaluates the learner based on his/her choices and how well the initial requirements of the exercise were covered, e.g. by displaying a summary of energy balance efficiency (Figure 7).

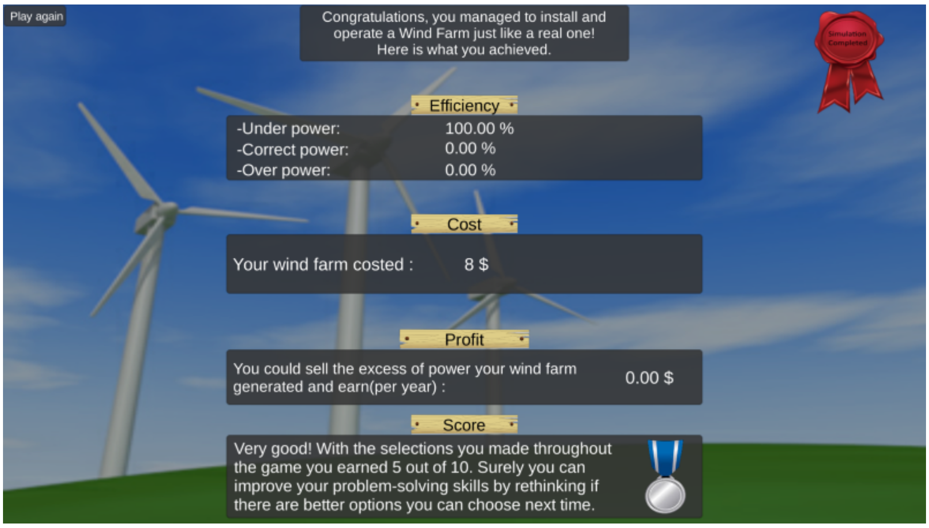

Fig. 7. The final scene evaluating players performance.

4 User evaluation

4.1 Evaluation protocol

In order to evaluate the labs we have conducted some surveys. We have let the learners play the labs and then 18 questions-statements were posed to them as shown in Table 1. The questionnaire is used to evaluate the learning content, the usability, the adoption, and the engagement with the virtual labs. A Likert-type scale was used to collect the data; each of eighteen questions was rated on a five-point scale ranking: i) strongly agree, ii) agree, iii) neutral, iv) disagree, and v) strongly disagree.

The *Chemistry Lab* was first tested, followed by the *Wind Energy Lab*. The first serious game was started with the entertainment instruction ("MISSION: Congratulations! Today is your first day in the Chemistry Laboratory. Lets produce some chemical compounds, by using the Labs equipment. Pay attention to your assistants advices."), while the second was started with the mission instruction ("Your team has undertaken to study the construction of a wind farm. The wind park should meet the energy needs of a village with the following characteristics: Population: 4.000, Households: 1.800, Requested power: 6MW".). Afterwards, the students filled out the questionnaire. There was no time restriction for playing and answering the questionnaires.

4.2 Results

The results presented here regard the survey on 40 individuals (19 to 48-years old, average: 23, 5% female, 95% male) from a Greek vocational training institute

Table 1. The statements on questionnaires.

Q1:	The content presented in the virtual lab is correct and well balanced.
Q2:	The virtual lab fits well with the curricula.
Q3:	The virtual lab presents the learning content in a relevant manner for the students.
Q4:	The quality of the learning content did not meet my expectations.
Q5:	It is difficult to integrate the virtual lab into a learning content.
Q6:	The learning material is presented in structure and complexity that suits the students' competencies.
Q7:	The user interface of the virtual lab (menus, buttons etc.) was easy to understand.
Q8:	I believe that the virtual lab will give the students a better understanding of the topic.
Q9:	The learning goals for the virtual lab are clear.
Q10:	I believe it will be hard for me to evaluate the student's performance in the virtual lab.
Q11:	I have a good sense of how the students will work with the virtual lab.
Q12:	The virtual lab supports differentiated learning.
Q13:	I would use the virtual lab in my teaching.
Q14:	I would like to change part of the virtual lab to better support my teaching.
Q15:	I believe students will find the virtual lab engaging.
Q16:	I believe students will find the virtual lab challenging.
Q17:	I believe students will enjoy using the virtual lab.
Q18:	I believe the virtual lab will stimulate the students' interest or curiosity in the subject.

with specialization in multimedia applications. These results regard the latest versions the labs. Their participation was volunteered and they all informed for a bonus grade in final exams, as a reward. The majority of participants declared great familiarity with desktop and web-based 3D games, but limited experience with virtual learning. Each student played the game alone following some general instructions that were displayed on a projector. The average playing time for each game was 40 minutes with an intermediate break of 15 minutes.

The statistics of the survey are shown in Table 2. Regarding the content and cognitive value of the virtual labs there is a general acceptance. In Q1, 65.0% of participants found the presented content in the virtual labs correct and well-balanced, while only one tester (2.5%) expressed a negative opinion. In addition, 62.5% of the volunteers were satisfied with the presentation of the learning material. More specific, the structure and the complexity suit the students competencies (Q6). There is no negative feedback in Q2 and Q3. Specifically, 67.5% thought that the virtual labs fit well with the curricula. The same percentage evaluated that the virtual labs present the learning content in a relevant manner for the students. The responses in Q5 and Q4 statements were balanced,

Table 2. The aggregated results.

Statement	**strongly agree**	**agree**	**neutral**	**disagree**	**strongly disagree**
Q1	22.5%	42.5%	32.5%	2.5%	0.0%
Q2	12.5%	50.0%	37.5%	0.0%	0.0%
Q3	10.0%	52.5%	37.5%	0.0%	0.0%
Q4	7.5%	20.0%	32.5%	37.5%	2.5%
Q5	10.0%	25.0%	32.5%	30.0%	2.5%
Q6	25.0%	37.5%	35.0%	2.5%	0.0%
Q7	42.5%	32.5%	22.5%	0.0%	2.5%
Q8	32.5%	47.5%	7.5%	10.0%	2.5%
Q9	27.5%	47.5%	20.0%	5.0%	0.0%
Q10	5.0%	12.5%	47.5%	25.0%	10.0%
Q11	15.0%	55.0%	20.0%	7.5%	2.5%
Q12	7.5%	55.0%	30.0%	5.0%	2.5%
Q13	25.0%	45.0%	20.0%	5.0%	5.0%
Q14	12.5%	42.5%	35.0%	10.0%	0.0%
Q15	17.5%	45.0%	32.5%	5.0%	0.0%
Q16	10.0%	35.0%	45.0%	7.5%	2.5%
Q17	17.5%	45.0%	27.5%	7.5%	2.5%
Q18	30.0%	47.5%	15.0%	5.0%	2.5%

which refer to users' expectations and virtual labs integration with the learning content.

From usability perspective, there is a positive evaluation. More specific, in Q7, 75.0% of participants expressed a positive opinion about the user interface of the virtual labs, while only 2.5% was against this statement. In Q8, 80.0% thought that the virtual labs will give the students a better understanding of the topics, while 12.5% disagreed. Moreover, 75.0% of participants supposed that the learning goals for the virtual labs were clear, in contrast with 5.0% that disagreed (Q9). The balanced results in Q10, risk any assessment compared with the contribution of the virtual labs in students' evaluation.

Regarding the adoption of the virtual labs by participants in the learning process, their general acceptance is detected. The percentage of dissidents is limited to 10.0%. Particularly, 70.0% of testers said in Q13, that they would use the virtual labs in their future teaching. The same percentage agreed with Q11, having a good sense of how the students will work with the virtual labs. In Q12, 62.5% of participants recognized the support in differentiated learning, by using the virtual labs. Moreover, 55.0% referred in Q14 that they would like to change part of the virtual lab to better support their teaching.

From engagement's perspective (Q18), a massive percentage of 77.5% admitted that the virtual labs will stimulate the students' interest or curiosity in the subject, while only 7.5% doubted. Regarding students' engagement with the virtual labs, in Q15, 62.5% was positively expressed, in contrast with 5.0%. In Q17, 62.5% believe that students will enjoy using the virtual lab, and 45.0% consider that these are challenging in Q16, while a 10.0% of participants are opposite to these statements.

5 Conclusions and future work

In this paper we presented the design and development of two virtual laboratories that support the educational process in STEM lessons. In addition, we have displayed the results of a quantitative user evaluation with 40 participants - specialists in 3D games. As concerns the content and cognitive value of the *Chemistry Lab*, and the *Wind Energy Lab*, it was rated positively, well balanced, and met the expectations. Regarding the usability, the navigation into the virtual environments was easy, and the graphical user interfaces were reliable. The virtual laboratories were tagged as engaging, challenging, and entertaining even with their mid-quality 3D graphics, due to their web-based orientation. Moreover, the adoption of these educational tools in the learning process was clearly expressed. In addition to the positive evaluation of these educational serious games, an important element that has emerged is that users would like to create and customize virtual laboratories themselves.

In ENVISAGE project have also developed a web-based authoring tool, taking advantage of recent 3D graphic technologies such as three.js[10]. The instructor is able to create the virtual environment, and design the learning context. The virtual lab can compiled in WebGL or standalone-desktop format through Unity3D game engine, and disseminated to students. However, the important thing is that the teacher will be able to adapt the educational lab appropriately, using the analysis of pupils' behavior [11].

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