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**GEA 2: A New Earth. Technical report on
designing and realizing a serious game for
supporting STEM teaching**

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Abstract—This document describes the realization of “Gea 2: A New Earth”, a serious game for supporting STEM teaching in high school, coping with both technological and pedagogical challenges, and thought as a supporting teaching tool to be used in classes, as an alternative to the more traditional frontal lessons.

Keywords: Unity ; serious game ; technology enhanced learning ; STEM

I. INTRODUCTION

A. Research context

The need to reshape and reconsider requirements for the new competences tailored for the new generations brings the attention to a necessary rethink in education. Fewer young people in fact take Science, Technology, Engineering and Mathematics (STEM) subject in schools, thus leading to a dramatic decline in the number of careers in the same fields. Learner centred approaches using ICT, achieving personalised and adaptive learning experiences are crucial to boost innovation in educational technologies.

In recent years we have witnessed an increase of interest towards the use of e-learning technologies and digital games for educational purposes. In particular, the research in a branch of Artificial Intelligence aiming at developing intelligent educational software, has recently been concentrated on computer-aided teaching tools known with the acronym ITS (Intelligent Tutoring Systems). Such systems aim at capturing and analysing the very knowledge that allows experts to develop an educational interaction in the first place. In this way such knowledge can then be explicitly represented and used in digital systems. An interaction is thus no longer defined a-priori by some knowledge, instead programs compose instructional interactions dynamically, computing decisions with respect to the knowledge they have been provided. This encoding of knowledge allows more intelligent, adaptive and effective behaviour in tutoring systems [1].

Computer-based instructional tools support a higher degree of individualization and custom-tailored content delivery simply not possible in traditional classrooms. This allows dynamic adaptation of the instructional system, providing specific support for the learner based on user models.

A Virtual Learning Environment (VLE) further extends ITSs capabilities by providing the learner with additional educational resources, such as multimedia material, communication tools, recommendation systems, and more. Moreover,

the possibility of interaction with other learners opens the door to new possibilities of e-learning scenarios. This approach has proven to achieve better academic results [2].

Research has highlighted motivational factors from computer/virtual games, visualization, and Human-Computer-Interaction (HCI) aspects that can greatly motivate the next-generation learner through Digital Game Based Learning (DGBL). Games are structured contexts, with clearly-defined rules, where players must overcome challenges and face opponents to achieve victory. Games can offer incredibly immersive and engaging environments where users learn by doing and improve skills and competences related to decision making, strategy, teamwork, social skills, leadership and collaboration. Serious Games (SG) focus on the design, development, use and application of games for purposes other than entertainment. In spite of the existing evidence of success, there is still a limited use of Serious Games. As a consequence of that, the quality of SGs has not met the expectations of educators and the use of games has not become as general as expected.

Literature Overview

However, as pointed out by certain authors [3] [4] [5], although games are believed to be motivationally and educationally effective, the empirical evidence to support this assumption is still limited and contradictory, particularly regarding the effectiveness of games for concrete educational purposes, given that prior studies have focused more on motivational aspects than on curricular content aspects and core academic benefits. More recently, certain research projects, namely TEEM (“Teachers Evaluating Educational Multimedia”) and CGE (“Computer Games in Education”), investigated the use of commercial games in schools, producing positive benefits mainly regarding skills development and motivation, whereas curricular-specific learning outcomes were rarely mentioned [3] [6]. Other studies and projects focused on games specifically designed for educational purposes, addressing their motivational impact, and, in certain cases, learning effectiveness. The E-GEMS (“Electronic Games for Education in Math and Science”) project demonstrated that games increased children’s motivation and academic achievement within mathematics and science education in grades 4-8 [7]. Nevertheless, the use of a language and mathematics game by students aged

8-12 years old revealed that many students were unable to articulate the underlying mathematical concepts [8]. [9] found that the use of games on portable devices led to improved motivation and learning outcomes compared to traditional teaching within primary school mathematics and reading, whereas a pilot evaluation of a mobile DGBL environment on animal behaviour with children aged 11-12 years old showed that they were enthusiastic about the experience [10].

The afore-presented overview of prior empirical research indicates several issues that need to be further investigated. Firstly, given the limited and equivocal prior findings on the learning effectiveness of DGBL, further empirical research within school settings is needed into the impact of DGBL on students, not only in terms of motivation, but also in terms of learning outcomes in relation to concrete curricular objectives within specific subject areas. Secondly, the greater part of prior research focuses on children, whereas the impact of DGBL on students during the critical time of adolescence has been less explored. Further research is needed especially concerning high school level, where the question of keeping students motivated in the learning process and maintaining their scholastic competence becomes more acute [11]. Thirdly, most prior studies that include control groups compare DGBL to traditional teaching. However, such comparisons with human tutoring imply that games are meant to totally replace classroom practice instead of complementing it [12].

The aim of our research is to give a contribution in the area of Technology Enhanced Learning (TEL). In this research we present a Serious Game developed as an immersive 3D Virtual Learning Environment. While there is an upsurge of interest in Serious Games, Virtual Learning Environments, Intelligent Tutoring Systems, etc., there has not been yet an evidence in combining all these aspect into one. That is probably due to the fact that each one of the afore mentioned single research is quite complex to implement. Our intuition is to lower the complexity of the single systems and to compose them together to have a global system that can easily manage different aspects of Technology Enhanced Learning.

The game, *Gea 2*, was completely designed and realized coping with the technological and pedagogical challenges discussed so far. The game aims at teaching STEM to students that approach for the first time such topics, and it has been thought of as a supporting teaching tool to be used in classes, as an alternative to the more traditional frontal lessons.

The need to realize from scratch a new SG derives from different boosts. In fact, although research on SGs have been very prolific in current and past years, major effort have been made in games targeted at primary and middle school. Another area in which SG are well explored is for training purpose with adults or at university level. In particular, there are very few SGs targeted at high school students, that is the target of our SG. Further, from a technological perspective, very often SG are concentrated on VLE or on ITS, it is very uncommon to find a SG that combine those two aspects [13].

II. DESIGN OF *Gea 2*

The first important decision that we have made since the beginning is that *Gea 2* is a Serious Game that should be used in class as a supporting teaching tool. The idea is that teachers use the SG together with their students in class, as an integral part of the lesson. The second important decision is that the game should be a role playing game and that it should, of course, address some of the so-called 21st century skills, a set of meta-competences, soft skills, communication and collaboration skills. Through role-playing, players learn how to inhabit the headspace of someone other than their primary ego identity, offering them the chance to develop a stronger sense of empathy. In this way, RPGs help encourage a sense of community, by teaching individuals to function as a group [14].

The game's plot is the following: a meteorite is approaching the Earth and very soon there will be an impact provoking earthquakes and tsunamis that will devastate continents. Students are part of a space mission and each one of them has a specific role (among Geologist, Physicist, Chemist, and Astrobiologist), with assigned tasks. The team's goal is to identify, among three, an exo-planet that is suitable for human life. The single objectives are related to the specific role. Once the student/player has accomplished his/her tasks, the team should compare the obtained individual results and discuss together to infer which is the best planet among the three available ones. In *Gea 2*, players should explore the 3D environment, which is formed by a spaceship and three simulation rooms, one for each planet. Players should collect some objects around the ship and gain access - answering correctly to quizzes - to the planets' simulation rooms. In the planets' simulation rooms player should solve the assigned task using interactive panels. They can seek for help in any moment, namely asking questions to the IPA (Intelligent Pedagogical Agent) or simply consulting some ad-hoc prepared materials (like video, articles, insight, simulation, etc.) external to the game but integral part of the VLE.

A complete vision of the game overall solution, starts coming out after discussion and critical thinking. Collaboration and communication are natural outcome of RPGs that are specifically addressed by *Gea 2*. In fact, player beside collaborate to reach common objectives, can communicate also via chat and can share their discoveries with the teacher and other players during the game. The latter, inspired by the Knowledge Sharing paradigm, has been design ad hoc for *Gea 2*.

Another important aspect that we have taken into account, in the design phase, was to have an interface both for students and teachers, unlike most serious games. We believe that teachers should not be reduced to just assist the players, or even be totally excluded. They should be active actors of the game, conserving their leading role of coordinator.

For this project we developed a three-tier system architecture. The first tier is the presentation tier, that hosts the teacher and the student workspace. The logic tier comprises the web services that allow the management of players, teachers,

gaming sessions, and the coordination of the teacher and the student workspaces. The data tier comprises the data persistence solutions and the data access layer.

A. Presentation Tier

Teacher Workspace: The Teacher workspace consists of three different applications: the Professor App (PA), the Professor Virtual Board (PVB), and Opedia®.

Professor App: *a web application developed for managing gaming sessions and classrooms, and to view the collected data about the students' in-game activities, in both past and ongoing sessions*

This application is essential by design. More in detail, teachers can:

- Register and login to the PA
- Choose the schools where they teach
- Add/Select a class where they teach
- Start/stop gaming session for each class
- See students' results in ongoing or previous sessions

A gaming session lasts four hours. When a teacher starts a gaming session, the PA generates a unique code (PIN) relative to that specific session. Such PIN can be used to start the PVB application and link it to that gaming session in the classroom.

Professor Virtual Board: *the teacher's tool to be used in the classroom for managing the gaming session, interacting with the students and controlling their progresses*

The PVB is designed to run on an interactive multimedia whiteboard. More in detail teachers can:

- Launch the PVB and link it to the current gaming session using the PIN already generated using the PA to
- Add new teams

Information about teams is permanently stored and retrieved in successive gaming sessions. At registration time students can then join a team. After teams have been created teachers can:

- Access information about the players (such as role, assigned task, score)
- Check the position of the players on the map
- Validate the notes of the players in the Knowledge Cloud

To enable a better cooperation among students, we have added the possibility for them to share ideas, thoughts and in-game discoveries they make with the team they belong to. Published notes are first visible only by the teacher, who can then validate them.

Opedia®: *a cloud platform that allows the sharing of all sort of didactic multimedia between teachers and students*

We will not discuss Opedia®, we just note that this off-the-shelf platform has been integrated into our VLE thanks to an agreement that we have made with its owner.

Student Workspace: The student workspace consists of two applications: a 3D Virtual Game (3DVG), and Opedia®.

Opedia® has been already described. Players can access it through the 3DVG and they can recover the insights available for their role.

3D Virtual Game: *The 3DVG is the core of the student workspace. Students become players when they first register to the game, join an existing team for their class, and choose a role*

Players, once registered, belong to a team. Once the teacher starts a new game session, players can start playing. In particular they can:

- login to the 3DVG
- explore the 3DVG
- recover 3D objects they need to solve the assigned task
- gain access to the simulation rooms answering quizzes
- enter the simulation rooms and find the interactive panels
- solve assigned tasks using interactive panels
- ask help in natural language to the IPA
- access insights on Opedia
- add notes
- chat with teammates

All the actions listed above can be performed by players in the sequence they like, following their own strategies except for a small set of actions forced by game mechanics. To further try the students' problem solving skills, we developed a quiz mechanic. Throughout the game, students are asked to answer correctly to some quizzes, in order to progress in the game. In fact, to gain access to the simulation rooms, players have to answer correctly to the relative quiz. However, players cannot access interactive panels to solve the assigned task if they have not collected the necessary objects, so they have to explore the 3D environment. Moreover, the player has to guess which are the right objects for the assigned experiments, choosing from the inventory, in order to unlock the interactive panel.

Most of the actions in the game permit to raise points. The score mechanism is an important part of the 3DVG because score deals with student evaluation. During the game, players are notified about their successful actions but they do not know the exact amount of points they earned. The score can be checked only asking the teacher to check the score in the Professor Virtual Board. Players, beside points, gain badges that can be accessed in the trophy room, that is one of the spaceship's rooms. This decision was taken to encourage a contact between the player and the teacher during the gaming session. In addition, on the PVB, it is possible to check the team score.

The Intelligent Pedagogical Agent is fully part of the 3DVG and guides the player through the game. The IPA that we have designed has two main functionalities. The first is to reply to questions asked in natural language: it can be thus classified as a Dialogue Management System (DMS). The second is to evaluate game progress and emotions expressed by the players during the game, in order to infer if the player needs help

and, if this is the case, provide unsolicited hints. The latter ability provides pedagogical intelligence to our IPA: we pass from an Intelligent Virtual Tutor implemented as a DMS to an Intelligent Pedagogical Agent.

B. Logic Tier

The logic tier offers the web services that permit to manage players and teachers, teams, gaming session, etc. These include registration, login, progress saving and resuming (including score, collected objects, solved quizzes, etc.), note publishing, chat, IPA, etc. The logic tier communicates via network with the presentation and the data tiers.

C. Data Tier

The data tier consists of a complex database where all data related to the different actors of the system are stored. In particular, the database also stores the knowledge of the IPA. We refer to the knowledge about a specific subject as being held by a NPC (Non Playable Character). Specifically we have four NPCs, one for each role the players can choose. In particular the NPC knowledge templates consist of a simple sequence of questions, answers and eventually suggestions.

III. REALIZATION OF *Gea 2*

We now present in detail the implementation of the design models discussed in the previous chapter. We will present the technical details of the whole system, following its three-tier architecture. In particular, the PVB and the 3DVG have been developed with the help of Unity, a cross-platform game engine providing useful functionalities such as a rendering engine for 2D and 3D graphics, a physics engine, sound, scripting, animation, networking, and video support for cinematics.

A. Presentation Tier

Teacher Workspace:

a) *Professor App:* The application has been developed using Spring MVC, a framework for developing web application based on Model-View-Controller pattern. It works by mapping Java methods and classes with specific URLs, managing different “view” types returned to the client. In particular, for implementing Views, we did not use standard JSPs provided by Java, but we took advantage of the template engine Thymeleaf. It is a software designed to combine one or more templates with a data model to produce one or more result documents. In addition, we used Ajax to send data to and retrieve from a server asynchronously (in the background) without interfering with the display and behaviour of the existing page.

To implement data persistence, we used an Object-Relational Mapping framework, Hibernate. An ORM is a technique for converting data between incompatible type systems in object-oriented programming languages.

The interface of the PA is depicted in 1. The teacher has a main tab where he or she can start or stop a gaming session for a specific class through a dedicated button, collect

the generated PIN number, and, through appropriate buttons, expand the lists of teams, students, and individual progress information for each class. The teacher is also provided with two separate tabs for adding or removing classes from his or her list.

b) *Professor Virtual Board:* When the teacher opens the PVB he or she is shown a welcome screen where the PIN number can be inserted. Doing so links the PVB to a specific gaming session. The system then shows the main interface.

On the bottom of the screen takes place the live 2D map of the game. The position of the players in the current gaming session is continuously updated and displayed as icons with a colour representing the role, and the player’s name. On the top left corner of the screen the teacher can scroll through the list of teams for the current class. By selecting one of the teams the system shows the list of players that have joined that specific team. When the teacher selects a student, the content of that same window changes to display the student’s information. In particular the teacher can check the student’s detailed score (i.e. for each category) or read his or her assigned task. The teacher can then view the team’s Knowledge Cloud and scroll through all the notes published by each player in that specific team, and accept or reject each one with dedicated buttons.

Student Workspace: The 3D Virtual Game: When the student first opens the game, he is welcomed by an introduction video displaying the logo of the game. He or she is then presented with the login or register screen.

c) *Registering:* In order to register, at first the student has to provide mandatory data like email address, password, first and last name, in appropriate text input fields. In the second registration screen, the student has to select his or her school from a dropdown menu of schools where the system has been deployed, then the class, and finally one of the teams created by the teacher in that class. Then, all the necessary data are sent to a dedicated web service, which sends back an authorization token.

Networking operations are performed using a utility class we developed, that offers public functions for HTTP methods (POST, GET, PUT, DELETE). In addition, student’s data, together with some other utility variables, are also stored for in-game referencing and processing in a GameManager class. It is a static class delegated to store all the relevant information about the player (e.g. the assigned task, boolean values for triggering first-time events, unlocked badges), and to perform the scene loading.

d) *Progress saving:* In-game progress is automatically saved. Each time the player achieves something (unlocks a badge, collects an object, or scores points), game progress is automatically uploaded to the server and stored in the database. A script is delegated to the management of the player’s progress data. On the other side, whenever the player logs into the game, his progress data is fetched from the server and stored in the GameManager and in the ScoreSystem. The game can thus be played seamlessly across different gaming sessions in class.

The screenshot shows a web browser window with the URL `appserver.dis.uniroma1.it:9998/professortool/`. The page has a header with 'Game@School', 'Home', 'Add class', 'Remove class', and a 'Sign out' button. The main content area displays a table for 'Class (Academic year)' with columns for 'Session', 'PIN', 'Expiration', and 'Teams'. Below this is a table for 'Name' and 'Score' for 'BLUE SKY'. Another table shows 'Full Name', 'Character', and 'Score' for 'Rasa Iagnocco' (geologist, 13.0). A final table shows 'Quiz', 'Task', 'Objects', 'Notes', 'Ipa', and 'Chat' scores for various users.

Class (Academic year)	Session	PIN	Expiration	Teams
1 F (2016/2017)	Stop	076593	09/02/2017 21:16:02	

Name	Score	Students
BLUE SKY	78.0	

Full Name	Character	Score
Rasa Iagnocco	geologist	13.0

Quiz	Task	Objects	Notes	Ipa	Chat
13.0	0.0	0.0	0.0	0.0	9.0

Full Name	Character	Score
Rocchi Gobbi	astro-biologist	13.0
Martinez Tomassacci	physicist	18.0
Gabriele Meleo	chemist	34.0

Fig. 1. Professor App

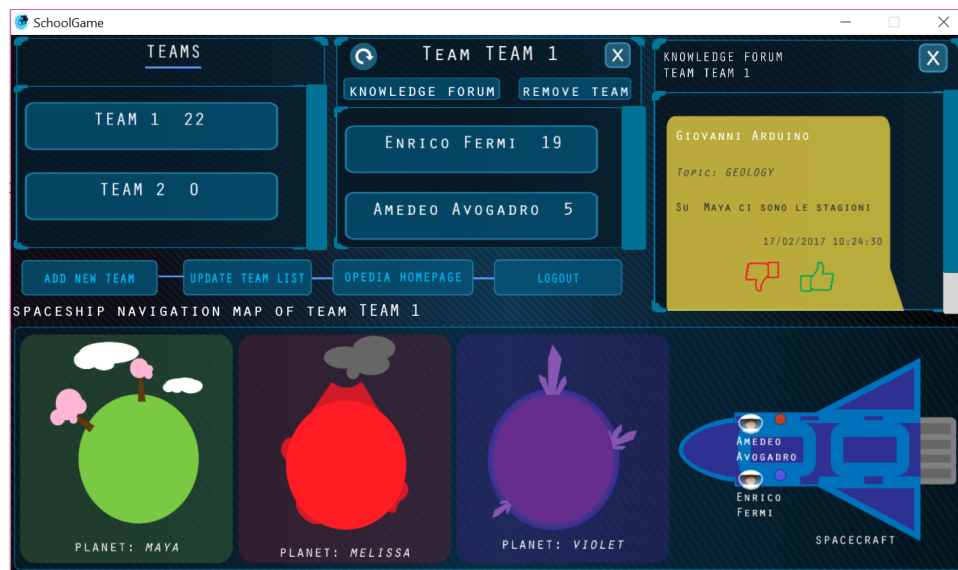


Fig. 2. Task Object Selection panel

e) *Playing the game:* Once the student is logged in, he or she starts his gaming experience from the spaceship (cf. Figure 3).

The user interface presents him with the controls on the bottom side of the screen. On the bottom left corner we have the movement joypad and the interaction button, whereas on the bottom right corner we have the sight joypad and the jump button. On the right side of the screen the player can find the button to access the chat to send text messages and emoticons to his or her teammates. On the top left corner of the screen is housed the inventory, which shows all the icons of the objects the player currently carries with him or her. On the top right corner of the screen the player finds four buttons. The first from the left shows a panel for inserting the answers to the tasks assigned to the player based on his or her role, the second accesses Opedia®, the third shows the Interactive Virtual Tutor interface where the player can

ask questions and get answers, and the fourth shows the note system panel, where the player can send notes and view the team's Knowledge Cloud.

The player can now explore the 3D environment, looking for objects, quizzes and any information to help him or her solve the assigned task. To ensure a positive reinforcement in learning, we provided the possibility to unlock badges as a result of some actions. When this happens, the player is immediately notified with an on-screen message that invites him to check his or her badges in the trophy room. In this room, all the badges the player has unlocked are displayed. When he or she approaches one of them, an on-screen message describes what it took to unlock that specific badge.

To progress in the game, the player has to enter the simulation rooms. In order to do so, he or she has to find the interactive monitors and answer some quizzes. Once he or she has answered correctly to the quiz, the entrance to the

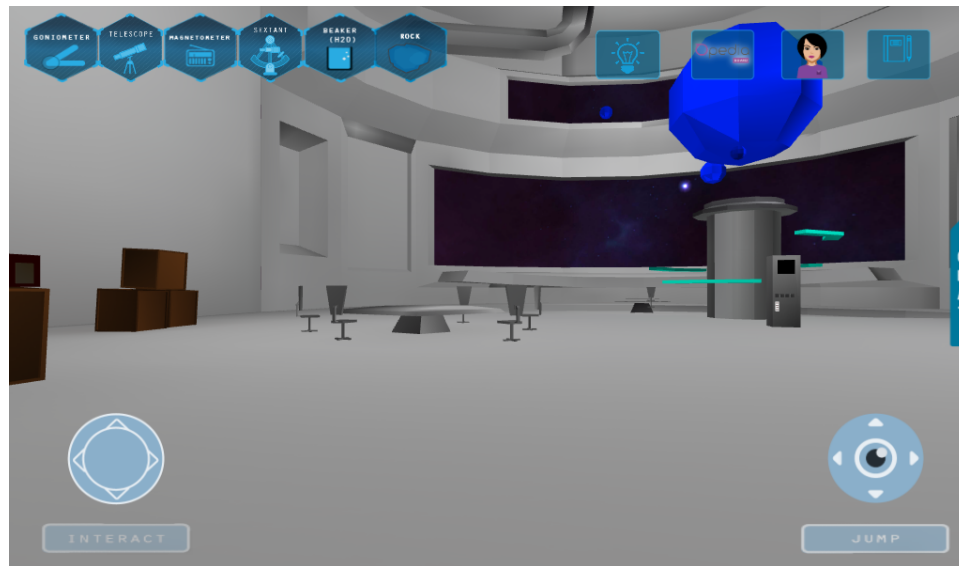


Fig. 3. View of the command centre in the spaceship

relative simulation room is unlocked.

Once a simulation room is accessed, the player has to find the interactive monitor to perform some kind of experiment. These experiments are the key to solve his or her assigned task. In order to ease the search for the interactive monitor in the large 3D environment, we put a light sign that indicates to the player where the monitor actually is.

Below we discuss in detail the components of the game we have previously presented.

f) Inventory System: The Inventory System, a software component implementing the singleton architectural pattern, is delegated to displaying the inventory to the player, adding objects found by the player, and removing objects used by experiments. The inventory items are displayed in the top left angle of the user interface.

A software component has also been developed to model inventory items, hosting fields representing the item id, a sound effect, and a reference to the Inventory System. The component also implements an animation function that makes the 3D model float in the air to make it more visible to the player. Whenever a player collides with a 3D item, it is added to the inventory.

g) Localization System: To implement the Localization System we developed a script capable of uploading the position of the player to a dedicated web service. An instance of this script is placed in every area the player can access. Whenever the player enters an area and the script instance is loaded, the latter uploads the position of the player to the server. The Professor Virtual Board can then fetch this data and update the live map accordingly.

h) Note System: To manage the sharing of notes we developed several scripts. When the user presses the Note System button from the top right corner of the user interface, the game presents a panel for composing the note. This panel

hosts an input field for inserting the text, a button to publish the note, a dropdown menu to select the subject of the note, a button to list the notes in the team's Knowledge Cloud, a dialogue panel for showing a feedback to the player, and a button to close the panel. Upon publishing, the system uploads the note to the server and notifies the user of the successful completion of the operation.

When the player opens the Note System, the same script queries the server for validated notes and performs the appropriate checks, and calls the relative functions for managing score and badges.

When the Knowledge Cloud panel is opened, the system fetches the notes from the server. To display the notes to the player, a note object is instantiated for each of the fetched notes, its fields are set, and it is anchored to a scroll view.

i) Unsolicited Hint System: In order to realize the pedagogical intervention of the IPA we have decided to monitor two distinct aspects of the players' behaviour in the game. The first aspect is strictly related to some parameters that monitor the advancement in the game, the second aspect is related to the emotions of the player.

To analyse the progress in gaming sessions, beside time that is a key factor, we decided to check two other important values. The first value is the overall score obtained by the player which reveals different actions undertaken in the game by the player himself. The other important value is how many questions the player has already asked to the IPA.

For what concerns the feeling of the player, we try to infer his or her emotions analysing the conversation with the IPA and the chat with other teammates. In chat message among teammates we monitor emoticons usage. To facilitate emoticons usage, we decided to use a limited numbers of emoticons: eight as the basic emotions.

The system can send the monitored data to the web service delegated to analyse it and provide the unsolicited hint if

needed. This function is called periodically, with an interval we have empirically set to three minutes.

The Unsolicited Hint System hosts a panel for displaying the hint to the player. To assess the validity of the unsolicited hints provided, i.e. the correctness of our algorithm, we added the possibility for the user to provide a feedback on the hint he receives, marking it as helpful or not.

j) *Chat System*: To enforce communication between teammates we provided the possibility for them to exchange text messages and emoticons in a dedicated chat group for each team. The user interface features an interactive panel that hosts an input field, a text container for displaying messages, a smaller panel showing all the emoticons, and a send button.

The chat is implemented through the use of the Photon Chat engine, which provides several functions used as callback. Photon Chat provides channels to group users or topics. To allow chat communication only among teammates, we used a channel for each team.

k) *Quiz System*: Whenever the player accesses a quiz panel, a script is called that loads the appropriate question and answer options dynamically from a text file, where they are indexed by a unique tag. In this way, questions can be changed by the (even inexperienced) teacher at will by simply editing such text file, without altering the code.

If the player answers correctly, the script plays a success sound and shows a panel with the objects he or she will need in the simulation room of the planet the quiz is relative to. If the answer is wrong, the script plays a failure sound and shows the wrong answer panel, then it updates a list of attempts the player made to answer the quiz. This is due to the fact that the score is calculated as a function of the number of attempts the player made before providing the correct answer.

l) *Animated Experiment Panels*: The 3D Virtual Game is multi-component and offers many player-game and player-player interaction possibilities. However, the core of the in-game interaction is the possibility to perform interactive experiment.

m) *Task object selection*: When the player first interacts with an experiment monitor, if he or she has collected all the items needed to unlock that specific experiment, a panel for the task object selection is shown. A script is attached to this panel that checks whether the first interaction has already been completed for this monitor. If so, the task object selection panel is hidden, and the experiment panel is shown. Otherwise, the script dynamically queries the Inventory System for the objects that the player actually possesses, and displays them.

The objects actually needed for each experiment are stored in a text file, identified by a unique tag.

When the player selects the objects he or she thinks are correct and presses the submit button, the main script evaluates the selected objects over the ones required to unlock the experiment. If they do not match, the player is notified about the mistake with an on-screen message and a failure sound. Otherwise, the objects are removed from the inventory, the first interaction for that monitor is marked as completed in

the MonitorSystem, the game plays a success sound and the interactive experiment panel is shown.

n) *Interactive experiments*: Every simulation room offers an interactive experiment panel for each of the available roles, a total of 12 experiments. Each experiment panel has its own scripts for implementing the interactive behaviour. Each panel features a window for the Interactive Virtual Tutor that explains to the player what has to be done. The IVT plays an audio file containing a spoken description of the task, and it is animated with the help of the Unity Crazy Talk plugin, creating the illusion of a talking character. Below the IVT window the experiment data are shown. The right half of the panel hosts a graphical animation of the experiment. The player can also read the task description on a dedicated panel by pressing the help button. To realize many of these interactive panels we took advantage of Unity's powerful Physics Engine.

Due to their high number will not discuss in detail all of the experiments, instead we will discuss a notable example.

o) *Astro-biologist task on planet Maya*: The experiment panel of the chemist player on planet Maya (cf. Figure 4) features a GameObject for the rotating planet and one for its star. The planet is kept rotating by constantly altering its x and y coordinates with the help of two Sin functions, out of phase by 90 degrees. Also, the rendering order of the GameObjects has been altered dynamically to create the illusion of the planet passing behind its star. In the left half of the panel, a table groups temperature values on equinoxes and solstices. On the planet's orbit, in place of the equinox and solstice points, four invisible trigger objects are placed. When the planet collides with these, the correspondent temperature value lights up. When the planet stops colliding with these triggers, the light goes off.

p) *Interactive Virtual Tutor*: In our system, the communication is implemented through an NLP algorithm based on an ad hoc text retrieval problem solver and on a Naïve Bayes text classifier with an inner product-based threshold criterion. What we have implemented is a variation of a text retrieval algorithm. The problem of selecting the right answer from a Knowledge Database (KDB) can be expressed formally similarly to an information retrieval problem [15].

The core of our system is an implementation of Naïve Bayes Text Classification [16], which is a probabilistic classification method based on Language Modelling under the hypothesis of words' conditional independence. This algorithm is an application of the Bayes Theorem, which allows the estimation of the probability that a collection's document is relevant for a query, given the sequence of words that make up the query itself. We then validate the answer chosen by the Naïve Bayes algorithm by applying a threshold criterion.

On the other side, in-game implementation of the Interactive Virtual Tutor is quite simple. A script is attached to a panel displaying an input field and a submit button, as well as a text field for displaying the IVT's answer. When the player composes a question and presses the submit button, the script sends the question as well as the player's role to a dedicated



Fig. 4. Astro-biologist task on planet Maya

web service. The latter queries the NPC database for the most pertinent answer and sends it back to the player, who can read it from the interactive panel.

q) Technical Challenges: Mobile Device Optimization and Performance Tweaks: As kids nowadays spend more time playing with smartphones and tablets than with gaming consoles, most mobile devices, however, are not optimized for gaming, as they are conceived as general-purpose computing platforms for everyday tasks and have mid-to-low end hardware. Tablets in particular have a hard time dealing with 3D games. Perhaps the most graphic-intensive and resource-demanding operation in games is lighting rendering. To enhance performance in our mobile game we used a technique known as “lightmapping”. A lightmap is a data structure in which the brightness of surfaces in a virtual scene is pre-calculated and stored in texture maps for later use.

When “baking” a “lightmap”, the effects of light on static objects in the scene are calculated and the results are written to textures which are overlaid on top of scene geometry to create the effect of lighting. These “lightmaps” can include both the direct light which strikes a surface and also the “indirect” light that bounces from other objects or surfaces within the scene [17].

B. Logic Tier

The web services of the logic tier have been implemented using the REST architectural style. Data and functionality are considered resources and are accessed using Uniform Resource Identifiers (URIs), typically links on the Web. The resources are acted upon by using a set of simple, well-defined operations. The REST architectural style is designed to use a stateless communication protocol, typically HTTP.

To implement the web services we took advantage of Jersey, an open source Java framework created by Oracle for developing RESTful web services according to JAX-RS is a

standard introduced by Oracle in order to provide support for the realization of web services according to the REST philosophy.

We now briefly present the web services we have developed for the system.

The *authentication* services use a security token mechanism. The *class* web services are related to all the operations that treat the class as a whole, and allow the creation and deletion of classes, starting or stopping a gaming session for a class, and listing the teams in a class. The *team* services allow the creation and deletion of teams, listing the notes in that team’s Knowledge Cloud, and listing the students that have joined that team. The *professor* services are used to manage teachers and the classes they teach to. They allow the creation, deletion, update and retrieval of teachers, and the addition or deletion of a class from their personal list of classes. The *note* services are related to the management of notes in a team’s Knowledge Cloud, providing their deletion, retrieval and validation by the teacher, who can accept or reject them as previously mentioned. The *school* services are used to recover information about available schools and classes for each school. In order to provide an identification number for schools we have used the unique key generated by the government to identify Italian schools. Finally, the *student* services deal with recovering and updating information about players during gaming sessions. In particular they allow the creation, deletion, and retrieval of a student, the creation and update of the game progress for each student, the deletion and addition of a team for each student, the creation and retrieval of notes, the creation and update of a player’s position, the addition of the question asked by the player to the IVT, the creation and update of the score for each player, and the provision of unsolicited hints.

C. Data Tier

The data tier is implemented as a relational database containing information about all the entities discussed in the previous sections.

Logic and data tier are strictly connected since many of the web services in the logic tier can access the database both for reading and writing data.

IV. VALIDATION OF *Gea 2*

Developing a Serious Game to enhance learning is a goal-directed process that aims at clearly defined and measured achievements and therefore must include a validation phase to provide an indication of the learning progress and outcomes.

However, learning is a complex construct making it difficult to measure, and determining whether a simulation or SG is effective at achieving the intended learning goals is a complex, time consuming, expensive, and difficult process (cf. [18] and [19]). Part of this difficulty stems from the open-ended nature inherent in video games making it difficult to collect data.

Nowadays the most common post-assessment technique consists in testing players competencies by means of a questionnaire or performing teacher evaluation. This method is the simplest to implement and the most cost-effective, however it depends on the opinions of the students and does not take into account all of the information about what really happened within the game.

In addition to enhanced learning outcomes and better didactic experiences that can be directly measured by means of targeted assessments, other factors can indirectly lead to more enjoyable and effective learning. In particular, Serious Games captivate players in a strong engagement, that has been associated with academic achievements. Thus, the level of engagement can also be used as an indicator of the learning that a Serious Game is capable of imparting.

A. First Test Run

The development of the first version of the game ended in November 2016. The first test run was conducted immediately afterwards. We collaborated with a secondary school in Rome, that provided two classes and a room that could host our tests. The testing process has been conducted in a real context of education. In this test run we worked with two classes both formed by 21 students. In Tables I and II we report the details of the classes and the lessons schedule and methods of work.

The 4 lessons took place in the school library, which was a rather big room. In order to prepare it for the tests, we had to make sure to provide internet access in the area. We would have had four teams composed by 4 students each approximately, resulting in 16 tablets simultaneously connected to the internet. To provide wireless internet access to tablets, and to enforce load balancing, we deployed three wireless access points in the room, placed in order to cover the area where the students would have taken place, and provided them with internet access with the help of a dedicated switch. To better guarantee load balancing, preventing the tablets to choose on their own which access point to connect to in case of a

reconnection attempt, we configured each access point to allow connections only by registered MAC addresses. In this way, tablets would automatically connect only to their respective access points. The Interactive Multimedia Whiteboard, on the other side, was simply cable connected to the main switch.

In the following paragraph we describe how the lessons were organized. It is important to mention that the teacher who had the four lessons was external to the class. Other two people assisted the teachers for technical help with the game.

The Test: The first run spanned over four lessons. During the first lesson the teacher introduced the game to the class briefly explaining roles, tasks and objectives.

After commenting the results with the class, students formed the teams and chose their roles. We decided that students should have played possibly in couples, so three teams were formed, with 7 players each. We valued the importance of letting students self-organize and, most importantly, decide their team name, in order to ensure a stronger sense of cooperation and individuality in the learning process.

To concentrate ourselves on the testing of the actual game and on the assessment of the learning outcomes, in the second lesson we provided the students with credentials to access pre-made player accounts. We then divided them per team, and they started playing the game for about 40 minutes, while the teacher followed the game progress using the PVB.

During the third lesson we divided students per role, in order to encourage collaboration and knowledge sharing among teams. We noticed that players started using some functionalities of the game starting from this lesson, such as asking questions to the IVT or publishing notes in the Knowledge Cloud. Opedia[®] was used as well, and students found the possibility to consult insights useful. This is probably due to the fact that in this lesson they were already familiar with the basic game mechanics, so they could explore other features of the game.

In the last lesson the students were let finalizing their answers to the tasks they had been assigned and arrive to a final decision for each team, then their scores were compared on the PA. Due to time constraints students were not able to discuss their findings during the game, so they could not finalize a team answer to the overall game task, that is finding the most suitable planet for human life. We then proceeded with the completion of the appreciation questionnaire.

a) *Questionnaire Results:* The questionnaire was composed of the following sections:

- 1) What you liked and what did you not like
- 2) Ease of use of the game
- 3) Use of the provided help
- 4) Didactic contents
- 5) For future development

In Table III we report and discuss some of the students' answers to questions from sections 1 and 2. Such sections dealt mainly with the more implementative aspects. Such aspects include the student perception of the game and the learning process, its interface, its level of engagement, and their overall appreciation of the gaming experience.

TABLE I
CLASSES DETAIL FOR THE FIRST TEST RUN

School Name	Classes	Students
ITI Pascal	1F (Scientific Institute)	21 (9 ♀, 12 ♂)
ITI Pascal	1N (Industrial and Technical Institute)	21 (6 ♀, 15 ♂)

TABLE II
FIRST TEST RUN SCHEDULE

Date	Classes	Methods
29/11/2016	1F — 1N	Game introduction, pre test
06/12/2016	1F — 1N	Play game
13/12/2016	1F — 1N	Play game
10/01/2017	1F — 1N	Game conclusions, post test

TABLE III
QUESTIONNAIRE RESULTS FROM TEST RUN NO. 1

Question	Yes, a lot	Yes, enough	Indiff.	Not much	Not at all
Did you enjoy playing the game?	2	19	7	2	3
Do you think that playing the game is more engaging than a traditional lesson?	11	16	2	2	2
Would you recommend to students from other classes to try the game?	7	11	9	2	4
Do you think you have learned by playing the game?	1	11	7	6	8
Do you think that playing the game has allowed you to learn faster?	1	10	12	3	7
Do you think the game interface is easy to use?	1	17	2	7	4
Do you think the multimedia whiteboard interface is useful?	7	8	8	5	3

b) Data Analysis: Looking at the questionnaire results we can see clearly how about 2/3 of students enjoyed playing the game. Most importantly, they found playing the game to be more engaging than traditional lectures. Only about 10% of students, in fact, gave a negative answer to this question. In addition, more than 50% of students would recommend playing the game to other students. However, whether they thought they had actually learned something by playing is uncertain. About the same number of students gave a positive and a negative answer to this question, with a slight advantage to the negative, the rest feeling indifferent. The same happened with the question whether they thought they had learned in a faster way with respect to traditional lectures. However, from a usability point of view we can be satisfied noting that more than 50% of students found the game interface to be easy to use, and the multimedia whiteboard interface to be useful in gaming sessions. The results from the first run were encouraging, however we had vast room for improvement in view of the second test run. In particular, for students' perception of being actually learning something by playing the game.

c) Bug Corrections: The main aspect that emerged during this phase was the weakness of the experiments in the simulation rooms. In the first version of the game, in fact, the experiment panels were static, i.e. they still allowed the player to change some variables and see how they influenced the final result, however they provided no visual feedback. The players lacked a sense of involvement in dealing only with numbers, as they did not have the perception of being actually performing

some kind of experiment. Moreover, some experiments did not provide any sort of interactivity at all. This limited the efficiency of the game-based learning process in a significant way. To deal with this weakness, we decided to provide the experiment panels with interactivity and animated graphical feedback for the player. In particular, for some experiments we just provided a graphical simulation of the process (e.g. the inclined plane), whereas some experiments for some roles had to change completely. The second version of the game featured animated and interactive experiment panels for every role.

B. Second Test Run

Following the same methodology, we performed a second test run with two new classes from the same institute, formed by 24 and 29 students. Details about classes and lessons schedule are reported in Tables IV and V.

We managed to arrange a classroom 3.0 with special furniture, in addition to the multimedia whiteboard. The furniture consisted in special chairs and desks, that gives teachers the possibility to easily work in groups and change class configuration when needed. The desks have in fact a trapezoidal form, so they can be aligned or put in circle. We used the latter configuration for the this test run.

Tablets, multimedia whiteboard and special furniture for the last run was provided after an agreement with the company Eugeni Tecnologie srl, the owner of Opedia[®], who gave us licences to use it for the experiments.

TABLE IV
CLASSED DETAIL FOR THE SECOND TEST RUN

School Name	Classes	Students
ITI Bernini	1H (Scientific Institute)	29 (9 ♀, 20 ♂)
ITI Bernini	1D (Industrial and Technical Institute)	24 (12 ♀, 12 ♂)

TABLE V
SECOND TEST RUN SCHEDULE

Date	Classes	Methods
13/02/2017	1H — 1D	Game introduction, pre test
20/02/2017	1H — 1D	Play game
27/02/2017	1H — 1D	Play game
06/03/2017	1H	Play game, game conclusions
13/03/2017	1H — 1D	Post test, questionnaire

Again, we provided internet access in the classroom through the employment of three wireless access points coordinated by a switch. The former provided also the same load balancing mechanism from the previous test run.

a) *Improvements in Gea 2 v.2*: Following the first test run, we got into a second development phase, where several improvements were introduced. Other than many small usability enhancements, we report the most important features we introduced.

We decided to insert a leveling mechanism in the game, that is, providing new quizzes when the player reaches a higher level. However, at the moment this feature is only supported, but not yet provided to the player.

To enhance critical thinking and problem solving skills in the students, we added a further step before unlocking the experiment panel in the simulation rooms. In addition to collecting the needed object for the task, the player has to select from his or her inventory which of them are the ones needed to perform that particular experiment, as described in III-A0m.

One of the most crucial improvements we introduced in the second version of the game is the Unsolicited Hints System. With this upgrade we provided the Interactive Virtual Tutor implemented as a Dialogue Management System with pedagogical intelligence, advancing it to an Intelligent Pedagogical Agent, able to decide on its own whether to help the player or not.

The Test: The second test run followed the same schedule of the first one, with the only exception being that this time we let students perform the registration phase on their own, and during the fourth lesson students were let finalizing their individual and team tasks. They divided per team and nominated a team master responsible for coordinating the team, collecting information from players with different roles and compiling the final report.

b) *Questionnaire Results*: Again, in Table VI we report and discuss some of the students' answers to questions from sections 1 and 2.

c) *Data Analysis*: Looking at the data presented in the previous section, we can assess an overall positive outcome of the test run. The majority of the students enjoyed playing the

game: in fact about 61% of students gave an explicit positive answer, while about 24% of students remained indifferent to the gaming experience. What is most important from this section, however, is that the overwhelming majority of students thought the game is more engaging than traditional lectures. Only roughly 15% of students, in fact, gave a negative answer to this question. We also gladly noted that more than 50% of students would recommend the game to other students.

Coming to the student perception of the learning process, we gladly noted that about 65% of students thought they have learned by playing the game. In particular, in this test run, differently from the previous one, students who thought they had learned something were 2 times those who thought they had not. However, whether students think they have learned in a faster way with respect to traditional lectures had them divided again. However, positive answers were the most numerous. Approximately, 40% of them gave a positive answer, 30% answered negatively, while the remaining 30%, the single answer that took more votes, felt no difference at all.

Positive answers were registered also for the interfaces of the whole system. Roughly 60% of students, in fact, found the game interface clear, while 70% of them found the PVB one useful. In particular, with respect to the previous test run, the number of the most positive answers to these questions had increased.

Looking at these results we can conclude that bug corrections and improvements in the second version of *Gea 2* contributed to a more effective gaming and learning experience.

V. CONCLUDING REMARKS

In recent years, the process of digitalization has finally affected teaching and learning in a deeper way. Digital games as well as other e-learning technologies are beginning to be used more seriously for educational purposes. Research in Artificial Intelligence, in particular, is giving useful insights for developing computer-aided teaching tools, known as Virtual Learning Environments, which allow a more intelligent, adaptive and effective behaviour in tutoring systems. To compensate the absence of human interaction, VLEs often feature Virtual Tutors, a kind of personal assistant that guides the

TABLE VI
QUESTIONNAIRE RESULTS FROM TEST RUN NO. 2

Question	Yes, a lot	Yes, enough	Indiff.	Not much	Not at all
Did you enjoy playing the game?	5	8	5	1	2
Do you think that playing the game is more engaging than a traditional lesson?	8	7	3	2	1
Would you recommend to students from other classes to try the game?	3	8	4	3	3
Do you think you have learned by playing the game?	3	11	0	2	5
Do you think that playing the game has allowed you to learn faster?	4	5	6	2	4
Do you think the game interface is easy to use?	2	10	3	3	3
Do you think the multimedia whiteboard interface is useful?	6	9	2	2	2

player. On the other side, VLEs enhance individualization and custom-tailored content delivery based on user models.

Following these premises, we have developed *Gea 2*, a Serious Game to be used as a supporting tool in class for teaching STEM in high school, as an integral part of the lesson. The pedagogical aims of *Gea 2* are to encourage the acquisition of meta competences and 21st century skills, beside learning STEM in a playful way. Students can explore a 3D environment that includes a spaceship and three simulation rooms, one for each planet they have to evaluate, looking for objects that unlock interactive experiments in the simulation rooms, and solving quizzes. To positively reinforce the learning experience, most of the actions in the game allow to score points and unlock badges. To solve their individual and team tasks, players can use help provided by an Interactive Virtual Tutor to which they can ask free questions in natural language. Underneath the game, an Intelligent Pedagogical Agent monitors the progress of the player and is capable of autonomously decide when to provide unsolicited help. Players can also share knowledge in their team's Knowledge Cloud, consult insights on a didactic cloud platform and chat with other teammates. The teacher follows the game progress and coordinates the session from a multimedia whiteboard.

We developed a three-tier system architecture. The first tier is the presentation tier, that hosts the teacher and the student workspace. The teacher workspace consists of two application and a cloud environment. The two applications run on the web and on an interactive whiteboard, while the cloud environment is provided by a third party. The student workspace consists of a 3D application that runs on mobile devices. The logic tier comprises the web services that allow the coordination of teacher and student workspaces. The data tier comprises the data persistence solutions and the data access layer that exposes the data.

We performed two test runs to assess the performance of the system in a real school scenario. In the first test run of the game we had 4 lessons with 2 classes in the school's library where we tested for the first time the whole game. In the second test run of the game, we had two classes of students in a classroom 3.0 environment. We had 5 lessons after which the students completed the same appreciation questionnaire.

Summarizing, from the data we collected in the three test

runs we can conclude that the game proved to be enjoyable and students would recommend it to others. Many of the game features are desirable by the vast majority of students, such as the possibility to have a personalised learning path and being able to chat with a dedicated virtual tutor also about personal matters. As of the AI algorithm performance underneath the IVT, students assessed it as effective. Most importantly, learning with the use of a virtual tutor proved to be significantly more effective than traditional lectures, both for STEM and humanities, with a slight advantage over the first. Overall, almost all the students in the sample found the game more engaging than traditional lectures, and felt to be learning while playing, although not necessarily in a faster way. In addition, the game interfaces, on both the 3DVG and the PVB, received positive feedback, as students found them clear enough and useful. In particular, looking at the results from the second test run, we can conclude that bug corrections and improvements in the second version of *Gea 2* contributed to a more effective gaming and learning experience.

a) Future Developments: When a player accesses an interactive experiment panel, the virtual tutor animates and the game plays an audio file that describes the experiment, giving the illusion of a talking character. As a future development, a Text-To-Speech engine could be included in order to improve the modularity of the system. In addition, we could animate the IVT also when providing answers to questions in its dedicated panel.

Another feature the students asked was the possibility to chat with the virtual tutor not just in a question-answer way, but also about personal matters. The game could further extend its NLP capabilities to support students in this respect.

A feature that an overwhelming majority of students (80%) wished we had provided was an avatar representing the player that they could customize. In a successive version of the game we could provide this feature in order to further reinforce the gaming experience in a positive way, deeply engaging students.

In addition, to allow students to play the game with their own devices, thus reducing the cost for schools to deploy the game in each classroom, it should be almost necessarily ported to iOS, to make it run also on non-Android devices (iPads).

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