The Table Mystery: An Augmented Reality Collaborative Game for Chemistry Education

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Abstract. Educational games constitute a major field inside the serious games ecosystem, attempting to educate the players, while entertaining them. Augmented Reality (AR) has found application in educational games, introducing properties that improve gameplay and that potentially produce unique educational affordances. In this study, we present the "Table Mystery" game, an under-development mystery-adventure game utilising Augmented Reality to provide an exciting and engaging educational experience related to chemistry and, more specifically, to the elements of the periodic table. The game is developed for the Science Centre in Oppland county, Norway (Vitensenteret Innlandet). The long-term study's purpose is to examine the effect of Augmented Reality on providing engaging and exciting, short-term educational experiences.

Keywords: Augmented Reality; educational games; game-based learning; periodic table;

1 Introduction

Educational games constitute a major field inside the serious games ecosystem, attempting to educate the players, while entertaining them. Over the years and through a large number of studies, it has been shown that educational games can convey higher levels of engagement, motivation and entertainment, compared to other forms of new or traditional, educational media [7, 8, 11]. Quinn states that the underlying model of his work [8] is that "the elements of learning and engagement of games can be aligned to create a synergy that can be exploited to systematically design compelling learning experiences".

More specifically, games have demonstrated to trigger active learner involvement through exploration, experimentation, competition and co-operation [12]. Video games utilise the elements of increased visualisation and challenged creativity to support learning and they, also, address the changing competences needed in the information age: self-regulation, information skills, networked cooperation, problem solving strategies and critical thinking [12].

Augmented Reality (AR) has found application in educational games, introducing properties that improve gameplay and that potentially produce unique educational affordances. AR can offer a high degree of context sensitivity, thus allowing players to gather data unique to their location, environment, and time,

including both real and simulated data [6]. The special characteristics that AR injects into the educational games suggest an array of new modes of interacting, such as instructional visualisation, context-sensitive investigation, or coupling physical space with instruction [6].

1.1 Contribution

In this study, we present an AR collaborative game for chemistry, named "The Table Mystery". The game is developed for the Science Centre in Oppland county, Norway (Vitensenteret Innlandet), a place that provides an exciting, fun, and interesting environment, packed with activities related to natural sciences, engineering and mathematics, for visitors, and mostly for students, of all ages. The contribution of the study is summarised as follows:

- Describe the development process of an AR educational game, aiming to examine the effect of Augmented Reality on providing engaging and exciting, short duration educational experiences.
- Implement prior field knowledge, examining the validity of previous findings related to the game development process.

2 Related Work

The game was developed based on the design principles for educational games, presented by Squire et al. in [9]. In this study, Squire et al. look across 15 game designs, performed over a two-years period and they identify seven core, heuristic design principles to assist game designers during the design process of educational games.

A number of game studies around AR in education was taken into consideration during the development process of the Table Mystery. The application of the AR technology in educational settings and, most imporantly, the pedagogical implications that emerged from this application provided the motivation for the current game study.

- *Environmental Detectives* is a multi-player, handheld augmented reality simulation game designed to support learning in late high school and early college environmental science, presented in the study of Klopfer and Squire [6]. The ndings of the game study suggested that a mature theory of Augmented Reality software may require a more robust theory of how space connects to previous understandings and future learning trajectories.
- *Mad City Mystery* is a mystery game where players use their argumentation skills through the virtual investigation to piece an explanation - investigates whether augmented reality games on handhelds can be used to engage students in scientic thinking (particularly argumentation) [10].
- The *Mystery at the Museum* game [5] - an interactive, collaborative mystery game, designed for synchronous play of groups of parents and children inside a museum setting - provided the conceptual model on which we based the design of the Table Mystery game. The game study concluded that the storyline, the

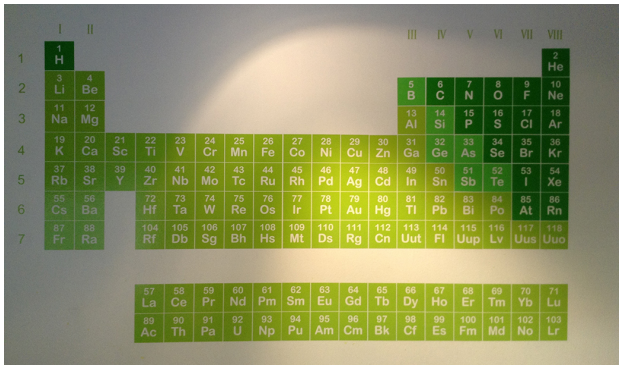

Fig. 1. The periodic table on the wall of the Science Centre in Oppland county, Norway (Vitensenteret Innlandet).

collaboration and the action of looking for "clues" resulted in deep and broad engagement, as well as the use of different player roles enhanced collaboration between teams.
– The *Castle Mendeleev game* [1], a simple question game, inspired the format of the Table Mystery's questions/riddles.

3 The Table Mystery Game

3.1 Brief Description

The Table Mystery game is a mystery-adventure game utilising Augmented Reality to provide an exciting and engaging educational experience related to chemistry and, more specifically, to the elements of the periodic table (Fig. 1). The game is developed for the Science Centre in Oppland county, Norway (Vitensenteret Innlandet).

3.2 Target Audience

The Table Mystery is developed for the Science Centre's student visitors, therefore the target audience is: students 11-13 years old with some basic knowledge of chemistry.

3.3 Goals

The ultimate goal of the Table Mystery's gaming experience is to provide a positive association between chemistry and learning as part of the suit of educational experiences provided by the Science Centre. That means that the game should focus on providing a pleasant and memorable experience around science, through educational content. The Table Mystery also aims to encourage collaboration within teams of students and between teams, in order to accomplish a common educational goal. As a side effect of playing the game, we are also aiming to familiarise the players with Augmented Reality.

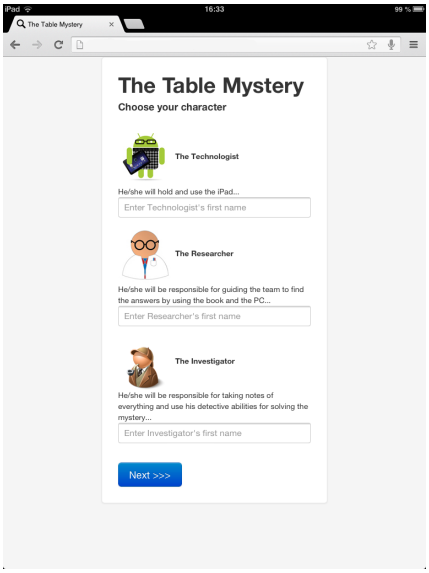

Fig. 2. A screenshot from the iPad mini of the "choose your character" page.

3.4 Game Plot

The fictitious premise of Table Mystery starts with a man that has amnesia. He is at a hospital and he tries to remember who he is and what happened. He needs the help of three teams of students to assist him remotely, since he has some scattered, chemistry-related memories, but he has no access to his encrypted notes. His notes are encrypted as 3D clues on a periodic table. Therefore, he describes his memories to the players via a tablet and they have to scan the periodic table (the chemical elements are used as AR markers) to discover 3D clues (Fig. 3), report it back and get further instructions for the next clue until the whole story is revealed. In the end, the man's identity is revealed and the players find out that the amnesia was caused by an accident after a conspiracy, attempting to prevent him from examining a new element.

3.5 Game Design

The design requirements set by the Science Centre were the following:

- the game must have scientific-educational content,
- the number of players must be between 9 and 12,
- the gaming session has to last approximately 20-35 minutes and
- the game has to take place inside a limited space where the periodic table is placed.

For the design of the Table Mystery game, we implemented four of the seven design principles (DP) for educational games, presented by Squire et al.[9]. The design choices were:

1. We designed an educational game by turning simulation into a simulation game (DP1). We took the action of reading and scanning through the periodic table and we added context, narrative backstory, and challenges and goals.
2. We designed the game's context by identifying contested spaces (DP3). Table Mystery is a spatially-based game by requirement, with its contested space to be in front of a large printout of the periodic table.
3. We developed an backstory of mystery and we ask from the players to identify the real-world applications of several chemical elements (DP5) in order to solve the mystery (what Squire et al. call "Using information to solve complex problems in simulated environments" [9]).
4. For encouraging players' collaboration, we applied the core game design mechanism of differentiating roles and distributing expertise (DP7, Fig. 2).

Additional design choices were also implemented, to further fulfil the design requirements:

5. We chose Augmented Reality as the most suitable technology for revealing what is "hidden" and for making the player feel special, like having a superpower, seeing things that are "invisible" to the naked eye. Thus, we invested on the "mystery" nature of the game and the enhancement of the "wow factor", since it had to be a memorable, however, short experience.
6. We chose to visualise the backstory using comic strips (Fig. 3), instead of plain text, in order to address to visual learners [2].
7. We chose the plot of the game to follow a linear structure. This gives us the ability to predict the players' moves and allocate resources to the different teams more fairly.

3.6 Game Structure & Flow

Each team has 3 players, each of whom plays as one of the 3 characters: the technologist, the researcher, and the investigator (Fig. 2). The technologist operates the iPad mini, the researcher is responsible for using the internet and/or the books to find the answers to the riddles, and the investigator is taking notes and documents everything for future use (i.e. the quiz). Each character plays a unique role, promoting the collaboration between the team's player in order to get past the various levels of the game. All the characters' qualifications are explained to the players prior to the game session.

Each team has an introductory tutorial and then the main story begins. The main story consists of four riddles, presented in a different order and with different phrasing for each team. The collaboration between teams, discussing about the potential solutions of the riddles is suggested, since the Table Mystery is not a competitive game. After the four riddles are solved, each team must answer four quiz questions, which then reveal a key code for each team. The key codes of all teams must be combined to unlock the final secret message which is the solution and the end of the game (Fig. 4).

A diagram of the gameplay flow is presented in Fig. 5.

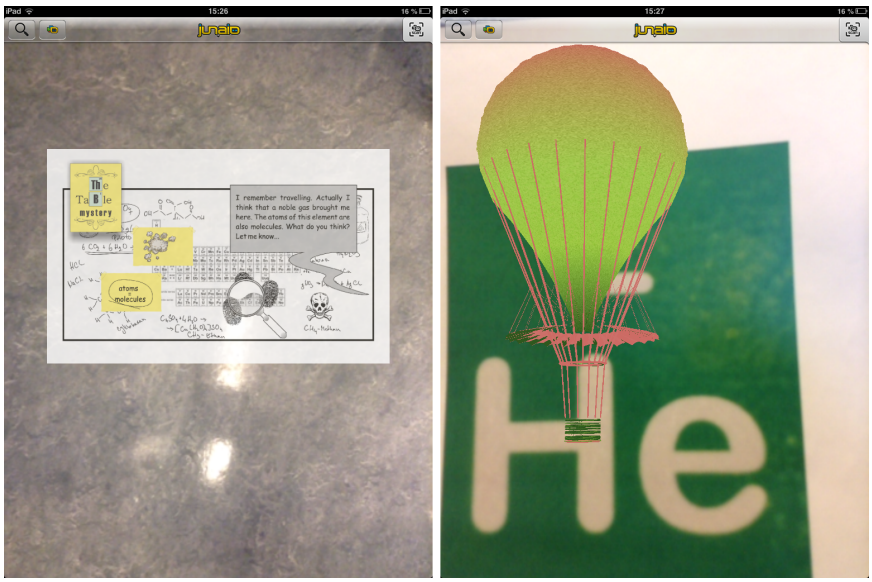

Fig. 3. A riddle, visualised as a comic strip *(left)* and a 3D model/clue appears when scanning the element that is the answer to the riddle *(right)*.

3.7 Materials & Cost

For the development of the game, a large print out of the periodic table was necessary. The alpha version of the game was developed using the AR platform and browser *Junaio* by *metaio GmbH*, connected to the university server, which hosted the game files. Each team was given an iPad mini, a chemistry book and a notebook. The teams also had access to a PC to search for chemistry-related answers.

The alpha version of the game was developed by one game designer/developer and one graphic designer, spending a total of 184 working hours. This excluded the user testing and feedback from the Science Centre staff.

4 Implementation & Results

We conducted a test gaming session with experts, including teachers and the staff of the Science Centre. The group was divided into two teams of three players, in order to check the suitability of the educational content of the game for our target group and to ensure its playability (Fig. 6). All of the experts had many years of experience of working with children/students and designing educational activities. The assessment of the experts' test gaming session was based on observation and open interviews, which were conducted after the gaming session.

During the experts' test gaming session study, we did not face any technical difficulties. The AR tracking performance of the AR markers worked accurately and the gaming session lasted approximately 25 minutes. The players experienced

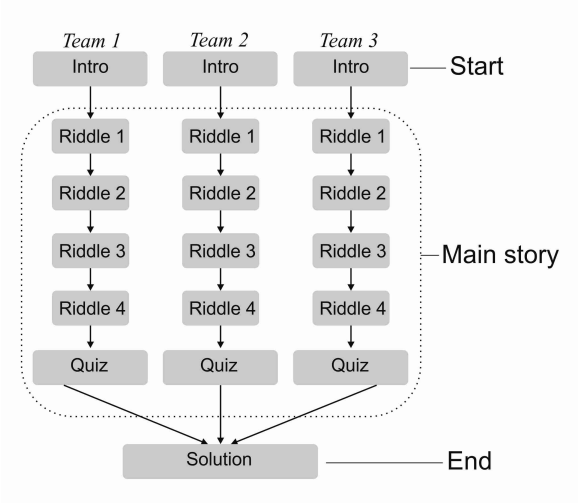

Fig. 4. The game structure of Table Mystery.

the "wow effect", since they were not totally familiar with Augmented Reality and had a pleasant time. Apart from the aforementioned riddle, the rest of the educational content was approved.

The results of the experts' test gaming session showed that some of the guidelines given during the tutorial need to be improved. Furthermore, the experts suggested that one of the sections of expositionary backstory needed to be broken into smaller chunks, given the attention span of students. The experts, also, expressed concerns over the difficulty of one of the riddles, which we considered a significant problem for player experience, therefore we decided to evaluate the riddle's difficulty level before going any further. To address the problem of the difficulty level, we shortly arranged for an informal follow-up test gaming session with one team of three 13-year old students. The riddles of the game were all tweaked to fit various difficulty levels, therefore we intended on seeing which difficulty level and riddle-style is more appealing to that sample of the target audience. The players completed the game with the help of the Science Centre staff, since they found difficulties to solve two of the riddles. The phrasing of the riddles was too scientific in some cases and the students had only one year of chemistry courses in their educational background. However, we found and agreed upon an acceptable difficulty level for our target group, which we plan to apply to all the riddles for the next round of the iterative design process.

The experts, also, suggested that we emphasise the characters of the players with physical props (e.g. a detective hat for the investigator, offering memorabilia at the end of the game, etc.), involve the character of a famous scientist in our backstory and, potentially, develop a riddle that is based on real experimentation with chemical elements, using mockup chemical substances.

Since the Table Mystery is still at the design phase, all the aforementioned findings and suggestions by the experts and by the group of students, will be

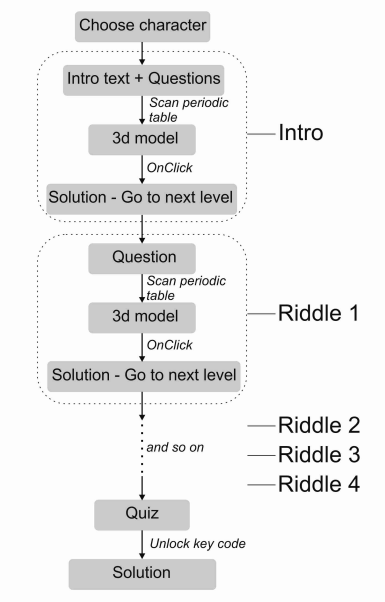

Fig. 5. The Table Mystery's gameplay.

taken into consideration for the implementation of the next version of the game and more test studies will follow, until we reach the final product.

5 Discussion

The motivation of this study is to examine the efficiency of Augmented Reality in creating an engaging and motivating educational environment. As part of the requirements, this game offers a short duration experience. It does not aim to provide significant knowlege transfer, but instead to create a psychological association between educational content and enjoyable experience, utilising a new medium with the flexibility to accomodate a variety of learning styles. Consequently, the examination of the hypothesis that AR can potentially create an engaging and enjoyable educational environment, is a first step towards deciding if focusing further on the educational content and on the knowledge transfer that the AR gaming environment can provide - in comparison with the traditional way of teaching - is a feasible and research-worthy future goal.

Even though the game does not aim to provide significant knowledge transfer and its goal is more experience-focused, we are planning to assess the game's efficiency both on knowledge tranfer and on user experience at the final usability testing stage. The knowledge about chemical elements and their everyday use, acquired by playing the game will be evaluated by a two-month follow-up quiz, similar to that at the last part of the main story of the game. We, also, plan to use the Game Experience Questionnaire (GEQ), which assesses game experience as

Fig. 6. Playing the Table Mystery game during the experts' test gaming session.

scores on seven components: Immersion, Flow, Competence, Positive and Negative Affect, Tension, and Challenge [4]. The establishment of an engaging and exciting AR setting can potentially help us to scale the described game model and to focus more on the educational character of the game and the knowledge transfer it provides.

As for the use of the AR technology, AR was chosen to demonstrate to young users the potentials of new interfaces that connect the digital world with real objects, offering a sense of "magic" and utilising the "wow factor". We consider that the familiarisation of young users with AR is of critical importance, since the increasing penetration of AR in everyday activities and the ongoing development of promising AR projects, like the Google Project Glass [3].

6 Conclusion

The Table Mystery is a gaming project, which focuses on contructing an engaging, playful and pleasant educational environment, further aiming at a small-scale knowledge transfer. The Table Mystery game study attempts to set the grounding for a larger study on AR educational games and so far it presents promising potentials, being reviewed and played by groups of experts and students, with positive results. More test gaming sessions, as well as future usability studies, will help to eliminate its problems and emphasise its power, through an iterative design process.

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