Educational Nanotechnology Video Game to Inspire Middle and High School Students to Pursue STEM Related Professional Careers

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Abstract—This Work in Progress Paper of the Research-to-Practice Category discusses a complementary learning tool to motivate students to pursue careers in Science, Technology, Engineering, and Math. Students from middle and high schools are experiencing a lack of interest, awareness and resources to pursue careers related to science and engineering. Knowing that education is a key factor for success, an initiative was developed to attract these students into STEM careers, by using the growing and emerging field of nanotechnology as a catalyst. In this research, an educational video game was developed to motivate students to pursue STEM careers and introduce them to the world of nanotechnology. The designed video game presents information about nanotechnology using different approaches, including accurate representations of nanotechnology and other concepts at nanoscale, an engaging storyline, and an interactive game experience to involve players into the lesson. All concepts and teaching strategies are based on the *Constructivism* and *Mindset Learning Theories*. The video game provides students the opportunity of having fun while learning from the interactive menu and platformer levels. It is expected that this educational video game significantly increases the number of students to pursue STEM related careers.

Keywords—nanotechnology, video game, education, STEM, constructivism, mindset, learning theories

I. INTRODUCTION

Science, Technology, Engineering, and Math (STEM) careers are considered growing and emerging, making them a sustainable choice for a professional career [1]-[2]. Furthermore, a STEM education consists of an integrated approach for instilling creative problem-solving techniques in students [3]. As recognized by Bybee, STEM education should increase students' understanding of how things work and improve their use of technologies, but as stated, a more coordinated strategy for pre-college education is needed, and it serves to benefit the economy by enticing more students into the study of STEM fields [3]-[4]. As a medium to attract middle and high school students to STEM majors, an educational nanotechnology video game called *Nanito and the Secrets of the Unknown Scale* is currently under development.

Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is around 1 to 100 nanometers [5], and includes the development and usage of materials, structures, devices, and systems that have unique properties because of their small size [6]. It is an innovative and emerging field that is currently being studied due to its benefit in health, environment, and technology. Thus, a nanotechnology-based video game that applies the *Constructivism* and *Mindset Learning Theories* as teaching strategies, in unison with the video game aspects, will be a motivational educational tool.

In the interactive main menu, the player is introduced to nanotechnology through the interaction with different objects. Firstly, the player can view the objects on a shelf at microscale and nanoscale through a microscope. Secondly, the player can learn about polymers [7] using a journal, which is accessed through computer panels in the menu. This knowledge can then be tested by taking a series of trivia games with different levels of difficulty.

The first level is a side-scrolling platformer. It is intended to teach students about ferrofluids, which are liquids that are polarized in the presence of a magnetic field. Moreover, it is focused on the treatment of cancer cells using ferrofluids. The second level consists of a solar-powered vehicle, which the student must drive around while learning about the benefits and applications of photovoltaics panels. These devices charge the car's battery, allowing the player to navigate through the maze where it is located. The third level is a side-scrolling endless runner focused in nano-electronic related concepts. The fourth level is still under development. However, it is designed to teach students about molecular and atomic manipulation, nanotextiles, and viscosity, all on molecular scale.

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Although this research is currently a work in progress, the video game designed accurately represents concepts of nanotechnology, and its learning aspect is supported by *Constructivism* and *Mindset Learning Theories*. Preliminary results were obtained to guide our experiments. The target audience consists of middle and high school students

II. Nanito Video Game Development

A. Design of the Aesthetical Aspects of the Video Game

Video games can captivate their audience by applying principles of design and color theories, such as *Proximity*. According to Farley, "using the principle of proximity, you'll find as you group those items that have something in common, and separate those items that don't, a clear visual hierarchy stands out on the page" [8]. In the designed video game, it is applied in the *Heads-Up Display,* which make the scenes look cohesive and organized.

Another principle of design is *Repetition*, which consist in repeating a single element many times in a design [9]. It can be appreciated through the repetition of certain terrains, such as the skin cell platforms and the walls (Fig. 1).

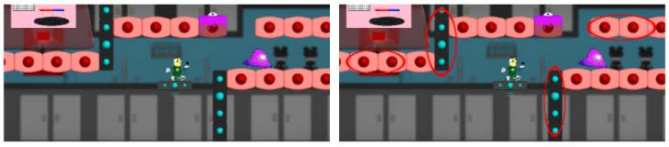

Fig. 1. Nanito first level (left) and examples of repetition (right)

On the other hand, there are color theories, such as *Color Harmony*, which consists of how things are arranged to compose something pleasing. "It engages the player and creates an inner sense of order, a balance in the visual experience" [10]. Furthermore, it is an equilibrium between colors, which can be achieved using the *Color Wheel* [11]. It is mostly used to identify complementary colors (Fig. 2) and analogous colors (Fig. 3) [10]-[11].

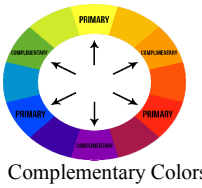

Fig. 2. Complementary Colors

Fig. 3. Analogous Colors

The current design is based on cel-shaded, which consists of drawing 2D/3D animated objects, sprites, or characters in solid colors or in a cartoony way. Cel-shaded games are often easier for computers to render than those pushing the boundaries of realism [12]-[13].

B. Software Requirements

For this game, it is assumed that the students will have access to a smart device with an interactive screen, or a computer with a connected keyboard. So far, it has been deployed for Android devices and Windows computers, and later on for iOS and MacOS devices.

C. Development Methodology

Unity is being used as the game engine, with scripts written in C#. For the testing process and quality control of the implemented game components, a "test while coding" approach is being applied.

III. Learning Theories

Learning theories are crucial in education and in teaching related projects because they set the foundation of how said projects are going to be developed. In the educational video game *Nanito and the Secrets of the Unknown Scale,* there are different learning theories applied in order to teach the player about nanotechnology in an effective way.

A. Constructivism Learning Theory

Based on constructivism, learning is a process of creating meaning from experience [14]. A person can create their own knowledge as long as they are provided with the right tools. This theory states that what people know of the world stems from their own experiences' interpretation [14]. Humans create meaning rather than acquiring it [14]-[15].

Students interact with the world by their experiences with the environment, such as exploring and manipulating objects, formulating questions, or performing activities and experiments. They build personal interpretations of the world based on their individual experiences and interactions [14]. As a result, students can better remember knowledge and concepts they discovered on their own [16]. Learners' internal representation of knowledge is constantly open to change. Therefore, to understand the learning which has taken place within an individual, the actual experience must be examined [14]. There are many different theories based around what constructivism is, and the designed video game implements several of them.

Vygotsky's "More Knowledgeable Other" (MKO) refers to "anyone who has a better understanding, or a higher ability level than the learner, with respect to a particular task, process, or concept" [17]. Having a relationship with a MKO empowers learning acquisition, since it allows the learner to acquire the knowledge from someone who is more experienced on the field. In *Nanito and the Secrets of the Unknown Scale*, the player plays as Nanito, on the laboratory of his older sister, Nanita. Throughout the game, Nanita acts as the "More Knowledgeable Other", providing tips and information to the player, while giving them the freedom of building up the knowledge on their own. The characters were designed in this manner to increase the number of women that pursue STEM careers, having Nanita as an inspiring role model.

Scaffolding is another theory based on constructivism, and it refers to a process in which students receive support as needed, which means that they can acquire knowledge with the intervention of an expert [18]. When students remain at a certain level of cognition, students tend to go beyond the original cognitive level more easily, if teachers or peers systematically provide guidelines or key instructions to them

[19]. As time passes, the learner creates their own knowledge, and will need less intervention from said expert, and eventually, the learner itself will become an expert on that field. In the game, Nanita will offer tutorials at the beginning of each stage, acting as the expert denoted on this theory. As the player progresses through the level, Nanita will interact with them on a lesser extent, and by the end of the stage, the player will not receive any guidance from Nanita. However, they will have enough knowledge to overcome the remaining challenges on their own.

B. *Mindset Learning Theory*

The Mindset Learning Theory by Carol Dweck explains how mindset can affect different aspects of people's lives [20]. She talks about how there are two types of mindset: fixed and growth. The fixed mindset states that people believe that they are born with a fixed amount of intelligence or talent, which cannot be changed or improved [20]. In growth mindset, a person believes that he/she can improve their skills with effort, leading them to accept challenges since they see them as opportunities to improve, and not as future failure [20].

In *Nanito and the Secrets of the Unknown Scale,* the growth mindset theory is applied in the trivia games and platformer levels. In the trivia games, growth mindset theory applies to effort-encouraging phrases that pop up when the player answers a question either correctly or incorrectly. For example, if the player answers correctly, a text is displayed telling them "You've learned so much", and if they were to answer incorrectly a text would read "You'll learn more with effort. Keep trying!". These effort-praising prompts are important to implement the growth mindset into the video game, since, according to the theory, any praise must target the effort that people put into their works or assignments rather than their qualities or abilities (intelligence or talent). As acknowledged by Dweck while researching students, "not only weren't they [students with growth mindset] discouraged by failure, they didn't even think they were failing. They thought they were learning" [20]. Hence, several tips from Nanita were implemented on the platformer levels to support the player throughout the game and promote a growth mindset.

IV. Video Game as a Complementary Learning Tool

There have been numerous studies that back up the effectivity of video games as educational tools when implemented in tandem with regular teaching methods. For example, del Pozo [22] shows that, when educational video games were played in pairs by students, it improved their retention and understanding of the lessons taught at the school, as opposed to those who only participated in the regular classes. Moshirnia and Israel [23] state that there are certain ways to present this information in video games which are significantly more effective at conveying the lesson than others. Specifically, educationally accurate sprites and continuous displays of information were more effective than informative pop-ups. Adachi and Willoughby [24] show that strategic video games, ones that are not fast paced and focus on puzzles, allow for great opportunities to let players develop problem solving skills; which, in turn, leads to improved academic performance. This approach would be much more appealing to younger audiences and would be a supplementary form of schoolwork that is perhaps easier for them to grasp.

This project pursues various objectives with the purpose of educating and inspiring middle and high school students to continue studying after they graduate. The project's main goal is to present the video game to middle and high school students to gather information on its effectivity. Ideally, it is expected that the demonstrations will result in a clarification of the hypothesis that the game is an effective and viable method of teaching nanotechnological concepts and inspires younger student bodies to pursue university studies in STEM fields. This hypothesis stems from the notions presented that similar achievements have been made using video games as complementary educational tools, as previously stated by del Pozo [22], Moshirnia and Israel [23], and Adachi and Willoughby [24].

The video game will be implemented as a complementary learning tool in schools with the characteristics of the target audience, and could be implemented in other environments with students interested in STEM fields. Teachers will provide students with modules related to the topic, but they can understand and acquire knowledge by their experiences throughout the game. They will learn about basic and complex concepts of nanotechnology, as well as their applications.

V. In Game Learning Concepts

A. *Nanotechnology Concepts Applied on the Video Game*

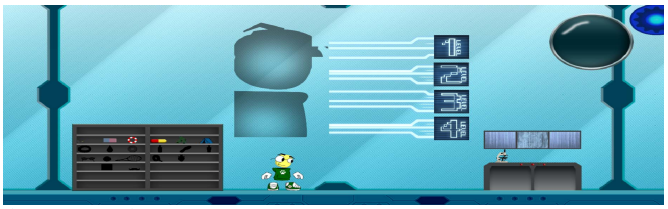

Fig. 4. Interactive Menu

The main concept that is taught on the Interactive Menu (Fig. 4) is about the polymers and its uses. A polymer is a substance composed of macromolecules, which are molecules built of a big number of small molecules linked together by covalent bonds [25]-[27]. There are examples provided in-game about where they are used on the industry or even on common items, which the player can see at microscale and nanoscale. This allows the player to understand that, at nanoscale, many objects can have similar properties since they are based on the same materials.

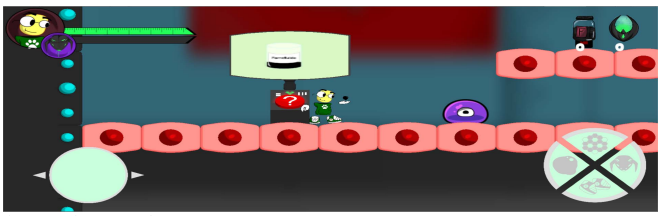

Fig. 5. First Level

Each platformer level approaches different applications of nanotechnology. The first level (Fig. 5) focuses on the physical properties of ferrofluids and their application on cancer treatment. Ferrofluids are colloidal suspensions of magnetic nanoparticles in a liquid carrier [28]. Due to their superparamagnetic properties, they can be used to create new devices and materials in the biomedical, mechanical, and electronics fields [29]. Since the pioneering work of R.K. Gilchrist *et al.*, magnetic particles have been used as complementary treatment for several types of tumors. In the game, this concept is displayed in the first level designs and mechanisms [28]. Ferrofluid is used to target animated cancer cells -the main enemy in the level- using a magnetic field emitter on Nanito's hand. Furthermore, interactive information consoles are spread throughout the level to teach students about ferrofluids and their applications.

Fig. 6. Second Level

In the second level (Fig. 6), the game demonstrates the employment of nanotechnology on solar power. In the third generation of photovoltaic cells, the addition of nanoparticles and nanoelectronics materials have improved the efficiency of solar energy panels [30]. In the game, Nanito drives a solar-powered car and explains principles of the photoelectric effect.

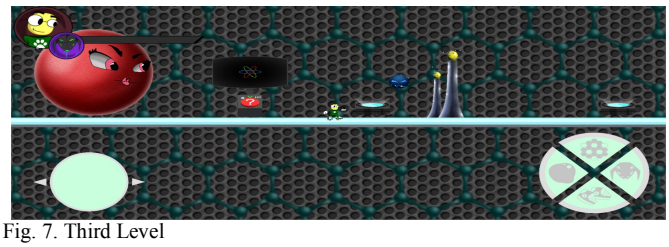
Fig. 7. Third Level

The third level (Fig. 7) centers around electric current and piezoelectric materials at nanoscale. Piezo-electronics are materials that produce an electric potential under mechanical stress, due to their molecular structure. Finally, the fourth level is designed to teach about nanofibers. These are one-dimensional nanomaterials that have extremely high specific surface area and can form highly porous mesh networks [31]-[32]. The focus of this last level is on how nanoscale manipulation aids on manufacturing of hydrophobic textiles, flame resistance finishes, and other elemental resistant coatings. In general, players are exposed to levels whose scenery, utilities, and obstacles reflect an application of nanotechnology.

VI. Effectivity of the Video Game Version

To be able to evaluate the player-game experience, the target audience's knowledge must be measured before and after having played the game. The development team will consider two strategies for data acquisition: in-game data acquisition and assessment at middle and high schools. The video game version contains different information stages in which the player can learn about the concepts involved in the level. To evaluate student learning, there are in-game challenges in platformer levels. Moreover, the interactive menu contains trivia games with different levels of difficulty. For evaluation purposes, before the release phase, student responses will be gathered anonymously and stored on each player's save file.

To measure the effectiveness of the designed video game as a nanotechnology inspired complementary learning tool, the team will perform an assessment consisting of a quantitative experimental study that will be held in educational environments at middle and high schools level. According to Earl R. Babbie, "quantitative methods emphasize objective measurements and the statistical, mathematical, or numerical analysis of data collected through polls, questionnaires, and surveys" [33]. The experimental study focuses on gathering numerical data by several demonstrations to the target audience. The first phase of the study consists of an analysis of the target audience. In this phase, a pre-test is going to be administered to each group. The second phase consists on the interventions with groups. There will be an experimental group 1, an experimental group 2, and a control group. The experimental group 1 will play the designed video game. To the experimental group 2, the development team would teach the in-game concepts as a normal lecture, expecting that students who play the game will learn the concepts better. The control group will remain without any intervention. In this phase, several factors will be considered: amount of time in the gaming interaction, surveys, number of students, range of ages, among others. After this phase, a post-test will be given.

The analysis of the target audience will allow the team to determine the effectiveness of the designed video game according to student's responses from their interactions with the technologies. The data analysis will consider the learned concepts, gameplay experience, difficulty levels, improvements to be performed, measures and statistical analysis of the video game methodology as a complementary educational tool, among other factors.

VII. Conclusion

The game is expected to present students with a wide range of nanotechnology concepts, from its metric scale, to various technologies, and several real-world applications. Each level is curated with accurate and entertaining representations of these concepts to properly engage the students and facilitate the learning of these advanced topics. Students should acquire previously unknown information on various scientific areas of study, be motivated by their newfound knowledge, and feel excited to learn more. Ultimately, they would find themselves inspired to continue learning about these or related STEM fields and choose to pursue a grade on any of them after high school.

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