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Designing the Periodic Table Solitaire Mobile App

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Abstract

The use of mobile applications in science education provides a series of benefits that enhance the learning experience and the understanding of scientific knowledge. Among these, interactivity, motivation, feedback, and personalized learning stand out. As part of a digital transition research project, mobile applications are being developed to enhance science teaching and learning. This study presents the design of the mobile app "Periodic Table Solitaire", whose objective is to familiarize users with the chemical elements of the Periodic Table, its structure, the families it comprises, and their relevance to daily life. This topic was chosen because the Periodic Table is an essential tool in chemistry, providing an organizational structure for chemical elements, aiding in understanding their properties, relationships, and behaviors. Various studies support that learning the Periodic Table through games yields educational benefits. "Periodic Table Solitaire" has been developed for Android using the Unity game engine and programmed in C#. The game's goal is to arrange all the cards into eight separate stacks, each corresponding to a family of the main groups (s and p-blocks) of the Periodic Table. The game features 43 cards, each representing the name and symbol of the chemical element, atomic number, group number, and an everyday object containing it (e.g., carbon in a pencil lead). All cards from the same family have a frame of the same color. Initially, the top of the screen displays eight spots for each family and a stack of covered cards. At the bottom of the screen, the cards are organized into six columns with one face-up card at the top of each column and one or more face-down cards below them. The player must move the cards between stacks and spaces to arrange them in ascending order by their atomic number. If the desired move is not possible, the player can uncover some of the face-down cards at the top of the screen. The game features various difficulty levels, each offering less information about the chemical element as the player progresses.

Keywords: *Mobile app, Educational Game, Chemistry, Periodic Table, Solitaire Game*

1. Introduction

The Periodic Table stands as a cornerstone in the realm of chemistry and broader scientific pursuits [1]. It serves as a comprehensive framework, organizing essential information about chemical elements, easing the prediction of their properties and interconnections [2], and laying the groundwork for a nuanced understanding and application of chemistry across diverse domains.

Despite its pivotal role, the understanding of the periodic table often poses challenges for certain students [3]. A primary hurdle arises from the wealth of information associated with each chemical element, encompassing aspects like name, chemical symbol, atomic number, atomic mass, and specific properties. This abundance of data can be daunting to memorize and prove challenging to retain. Additional complexities are related to technical language, interpreting specific symbolism, and comprehending its intricate organization. Students may also grapple with the dual concept of a chemical element: one conceived abstractly as a type of atom, and the other understood as a real substance present in everyday life and/or laboratory settings [4], [5].

The complexity of the subject matter can result in an initial lack of interest among certain students. Consequently, the manner in which the Periodic Table is introduced in the classroom or the materials utilized for its study holds significant sway over students' ease of comprehension [6]. An educational approach that integrates interactivity and practical applications, connecting the Periodic Table to students' daily lives, has the potential to alleviate these challenges. In this context, existing literature encompasses studies that establish a correlation between enhanced learning of chemical elements

and their application in everyday settings, such as within a household [7], in food [8], or in the components of a car [9].

Different reports predict a surge in the use and integration of devices and applications within the educational landscape, marking a quality-driven shift with an innovative essence. The Horizon Report [10], a collaborative effort by global specialists aimed at identifying and delineating emerging and disruptive technologies impacting teaching, learning, and research, notably underscored Mobile Learning in its ninth edition [11]. Within the educational domain, the adoption of digital technologies stands as a catalyst for innovation for both educators and students, elevating educational standards as they endeavor to reshape curricula, methodologies, and modes of knowledge dissemination, ushering in fresh alternatives for teaching and learning.

The integration of mobile applications with a gamified approach holds the potential to be an ideal resource for learning the Periodic Table, as it combines the advantages of technology with those of educational games. The use of mobile applications in science education provides a series of benefits that enhance the learning experience and the understanding of scientific knowledge. Among these, interactivity, motivation, feedback, and personalized learning stand out [12]. Gamification, on the other hand, focuses on the use of game design elements in non-game contexts [13], [14]. It enhances motivation by presenting content in a 'wrapper' (the game) that captures students' attention and encourages them to invest time in the proposed activities [15]. Other advantages of using games include promoting active, cooperative, and competitive learning, as well as fostering creativity and imagination. Additionally, they help build relationships with peers, addressing emotions, self-control, or task concentration, aspects that enhance the classroom environment. The use of educational games promotes the development of critical thinking and generates positive perceptions towards science, thereby contributing to improved learning [16].

Previous contributions to mobile applications for learning the Periodic Table include the work of Ewais et al. [17] and Franco-Mariscal et al. [18], among others. Ewais et al. [17] show the potential adoption of mobile learning technology in teaching a chemistry course, facilitating students' understanding of the Periodic Table, chemical element properties, and their interactions. Moreover, their study highlights the feasibility of integrating the proposed mobile application into the elementary school chemistry curriculum. Conversely, Franco-Mariscal et al.'s [18] mobile application, Elemental Home, encourages Periodic Table learning by identifying chemical elements within various everyday objects found in a typical household.

In this context, this work is situated within the research project R&D&i TED2021-130102B-I00 funded by the Government of Spain. The project aims to develop mobile applications based on gamification (serious games) to enhance the digital transition in science education. This paper specifically introduces the design of the mobile application Periodic Table Solitaire, a product of this overarching project.

2. Design of the Mobile Application

This section describes the design of the mobile application, focusing on the objective and target audience, the application's interface, card design, game rules, levels of learning, and the tools employed for the application's development.

2.1. Objective and Target Audience

The mobile application Periodic Table Solitaire is a serious game designed for teaching and learning chemistry across all educational levels. Its primary objective is to facilitate the understanding of the families of chemical elements in the Periodic Table, while also illustrating the relationship between chemical elements and daily life.

The game is based on the rules of the classic solitaire card game and involves forming the eight main s and p-block families on the Periodic Table: alkali metals, alkaline earth metals, boron family, carbon group, nitrogen group, chalcogens, halogens, and noble gases.

The target audience for the game includes students in the early chemistry courses at both non-university and university levels, as well as in-service or pre-service teachers at these educational levels. Additionally, the game is suitable for anyone with an interest in chemistry. The game language is Spanish.

2.2. Application Interface

The mobile application consists of two interfaces: a first access interface and a second main interface. Upon registration, users access the first interface, which comprises five buttons (figure 1). The first three buttons allow the player to choose the game level as beginner, intermediate, or advanced. This interface also includes a tutorial button with game instructions and another button providing information about the application's development and acknowledgments.

Figure 1. Access Interface of the Periodic Table Solitaire Game.

Once the game level is selected, users access the main interface of the application (figure 2). As depicted, it consists of a game board, cards, foundations, a card deck, and various buttons, elements that we will describe in detail shortly.

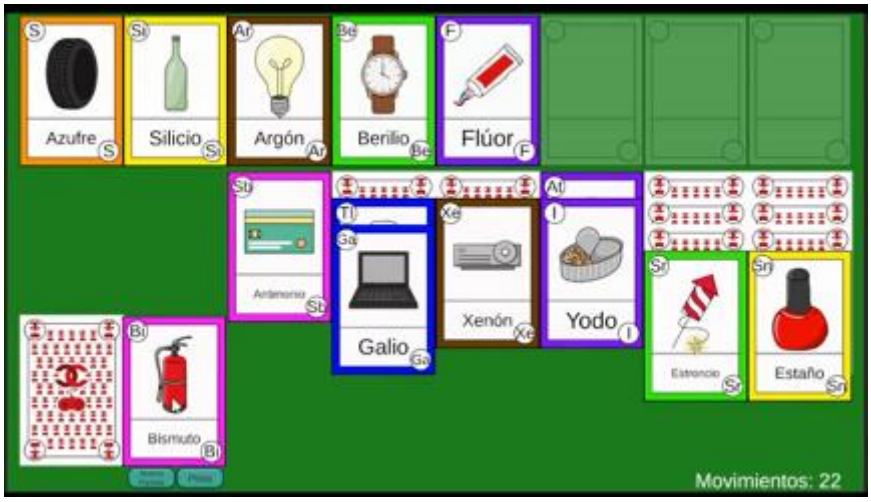

Figure 2. Main interface of the application for the intermediate level.

- **Game board:** Displayed in green, this is the central area where the game unfolds, comprising six columns of cards.
- **Cards:** The fundamental elements of the game, arranged in six columns on the board. The objective is to organize them in ascending sequences based on the families of chemical elements across eight upper areas known as foundations. Each column has a varying number of cards, with only the first card visible. The first column has one card, the second has two, the third has three, and so forth up to the sixth column.
- **Foundations:** Eight areas located at the top of the screen where the player must strategically organize the cards by chemical families in ascending order. Winning the game is achieved when all cards are successfully moved to these foundations.
- **Card deck:** Deck positioned in the bottom left corner, with all cards except the top one hidden. This deck is utilized to introduce new cards onto the board.
- **Buttons:** Two buttons in the bottom left corner of the interface empower players to seek hints or initiate a new game. The hint button grants access to a Periodic Table, allowing players to consult the placement of chemical elements within each family.
- **Scoring and moves:** Upon completion, the player's elapsed time for completing the game is showcased, along with a comparison against other players' times. Additionally, players can monitor the number of moves executed during the game at the bottom right of the screen.

2.3. Card Design

The game features 43 cards, each representing an element displaying its name, chemical symbol, atomic number, and an object or material from everyday life where it is found. Additionally, the family to which the element belongs is represented by a color-coded frame. When the cards are stacked, only the chemical symbol, atomic number, and the family's color frame are visible.

Figure 3 illustrates several cards. For instance, the card for the element fluorine showcases the position and meaning of the information presented on each card.

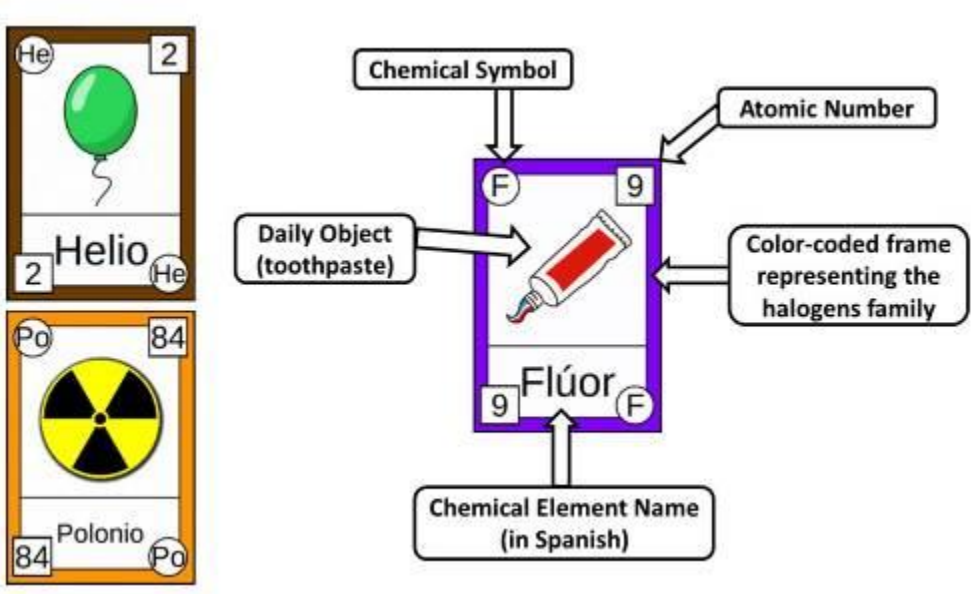

Figure 3. Examples of cards from the Periodic Table Solitaire game.

Table 1 compiles, for each family of elements included in the game, the materials or objects from everyday life that represent each of the elements.

Table 1. Objects and materials in which each chemical element is found.

Family 1 (Alkali metals) (red frame)		**Family 2 (Alkaline earth metals)** (green frame)	
Lithium	Batteries	*Beriyllium*	Wristwatch spring
Sodium	Streetlight	*Magnesium*	Racing bicycle
Potassium	Fertilizer	*Calcium*	Milk
Rubidium	Fireworks	*Strontium*	Fireworks
Caesium	Photoelectric cell of an elevator	*Barium*	Rat poison
		Radium	Radioactive element
Francium	Radioactive element		
Family 3 (Boron family) (blue frame)		**Family 4 (Carbon group)** (yellow frame)	
Boron	Tennis racket	*Carbon*	Diamond
Aluminium	Window frame	*Silicon*	Glass bottle
Gallium	Computer memory	*Germanium*	Wide-angle lens for cameras
Indium	Solar panel	*Tin*	Nail polish
Thallium	Insecticide	*Lead*	Car battery
Family 5 (Nitrogen group) (pink frame)		**Family 6 (Chalcogens)** (orange frame)	
Nitrogen	Ammonia	*Oxygen*	Combustion
Phosphorus	Matchstick	*Sulphur*	Vulcanization of tire rubber
Arsenic	Pellets (for shotguns)	*Selenium*	Antidandruff shampo
Antimony	Credit card chip	*Tellurium*	Vulcanization of tire rubber
Bismuth	Fire extinguisher	*Polonium*	Radioactive element
Family 7 (Halogens) (violet frame)		**Family 8 (Noble gases)** (brown frame)	
Fluorine	Toothpaste	*Helium*	Fair balloon gas
Chlorine	Salt	*Neon*	Neon bulb
Bromine	Photographic film	*Argon*	Incandescent bulb gas
Iodine	Clams	*Krypton*	Fluorescent lamp gas
Astatine	Radioactive element	*Xenon*	Projector
		Radon	Radioactive gas entering homes thorugh ground materials

2.4. Game Rules

The player must form the different families in the foundation area. To achieve this, it is required to complete the families following the ascending order of the atomic numbers of the elements, arranging all the elements consecutively. Thus, if at the beginning of the game, any of the visible cards is the first element of any of the families (lithium, beryllium, boron, carbon, nitrogen, oxygen, fluorine, or helium), it must be moved to the foundation area.

Figure 4 illustrates the arrangement of the cards at a specific moment in a game. Let's observe how the formation of the alkaline earth metals family (beryllium-magnesium-calcium-strontium-barium-radium) takes place in the third foundation area. At this moment, we have the second element of this family (magnesium) in this position, which means that directly below this card is beryllium, being the first element of the same family. In this situation, it would not be viable to place strontium, just revealed in the deck, on top of magnesium, as it is not the immediately following element in the family, and the prior presence of calcium is required. For the same reason, radium (in the fifth column) cannot be placed on magnesium, so cards need to continue to be drawn from the deck to complete this family.

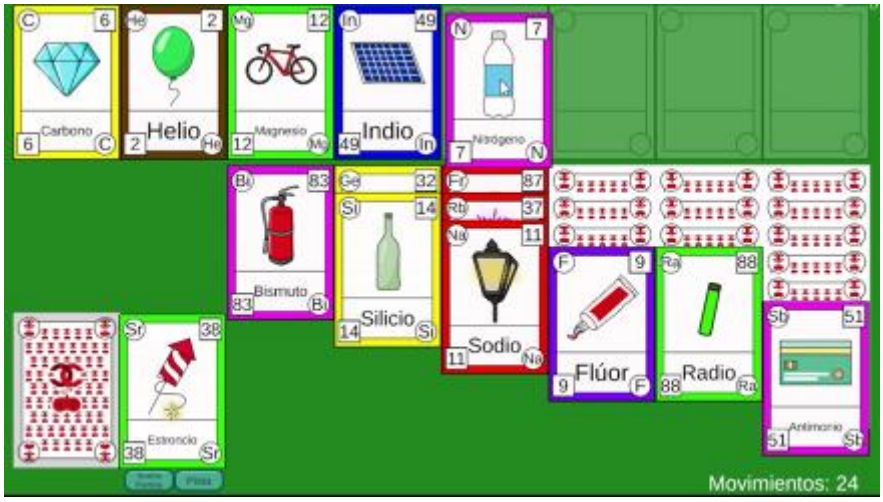

Figure 4. Example of a game to illustrate the rules of the game at the initial level.

The cards from the six columns and those uncovered from the deck, when movements are not possible, can be moved among the six piles following these two rules:

(1) Cards must belong to the same family.

(2) A card can only be placed on another if it has a lower atomic number, not necessarily the immediately preceding one.

For instance, figure 4 shows how the player has made different strategic moves to position sodium (Z = 11) on top of rubidium (Z = 37) in the third column, and the latter on top of francium (Z = 87). This arrangement is feasible because they meet the requirement of belonging to the same family (alkali metals), and moreover, the element placed on top has a lower atomic number. As seen, the rules allow placing them in these columns with an order that does not correspond to the complete sequence of that family (lithium-sodium-potassium-rubidium-cesium-francium).

Furthermore, within the six columns, the movement of several cards at once to another column is allowed. For instance, if in one column there were cesium (Z = 55) and in another column the combination rubidium (Z = 37) and sodium (Z = 11) (outermost card), it would be allowed to move the rubidium and sodium cards onto caesium, resulting in the arrangement Cs-Rb-Na.

2.5. Levels of Learning

The game features three difficulty levels, each offering less information about the chemical element as the player progresses.

- **Initial level:** The cards display information such as the name of the element, its chemical symbol, the atomic number, the everyday life object it is found in, and the color frame representing the family.
- **Intermediate level:** The cards present the same information as in the initial level, except for the atomic number (see figure 2).
- **Advanced level:** The cards display the name of the element, its symbol, and the everyday life object. The atomic number is not visible, and the family to which they belong is not identified, as all cards have the same gray color frame.

The levels are unlocked once the previous levels have been successfully completed, and they remain available at all times.

2.6. Tools for Application Development

The application has been designed for Android mobile devices and has been developed with the collaboration of a team that includes researchers in science education (the authors of this work), a programmer, and a graphic designer. In the initial phase, the game was developed as a prototype, meaning without sound or animations, which would require the use of specialized tools for such tasks.

The game engine used was Unity, created by Unity Technology, which employs OpenGL for the Windows operating system. Unity was chosen for its versatility and user-friendly interface. Unity allows the creation of both 2D and 3D games and requires basic programming knowledge.

The development environment for programming its components, features, and mechanics incorporated into the game was done using the C# programming language and PHP for connecting to the database.

The images used for the cards were created by a graphic designer using the Sketchbook program.

3. Final Considerations

This work introduces the design of a prototype for the game Periodic Table Solitaire, with the primary goal of enhancing students' knowledge about the chemical elements found in the Periodic Table. The emphasis is placed on comprehending their categorization into various element families, thereby facilitating a deeper understanding of patterns related to physical and chemical properties, the number of electrons in the valence shell, oxidation states, electronic configuration, and more. Additionally, the application aims to forge connections between the presence of chemical elements in everyday life, offering concrete examples of objects and materials where these elements play pivotal roles. The overarching objective is to cultivate awareness regarding the profound importance of chemistry in our daily lives.

The application has been meticulously designed, aligning with the key characteristic of a serious game, where the educational content takes precedence over entertainment, which assumes a secondary role. The design ensures that both fundamental components and game mechanics actively engage students in chemical concepts, fostering a learning experience where players acquire knowledge through practical application as they progress through the game.

4. Acknowledgements

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