Game-Based Learning to Enhance the Awareness on Raw Materials Necessary for the Energy Transition

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Abstract

The European Union is setting the transition to the circular economy that aims to give a use-life as long as possible to goods, in order to reduce the use of fossil fuels and primary raw materials (RMs). This change needs citizens to be aware of the importance of RMs for the transition to renewable energies. To trigger the students' interest in RMs (10-18 age range), the game-based learning methodology has been chosen and a duel card game titled "Raw Materials Fight" has been developed. The latter is inspired by other duel card games very popular among the selected target age (e.g. Yu-Gi-Oh!, Magic, Pokemon, etc.) but with the aim to teach the importance of many RMs in connection to the transition from fossil fuels to renewable energies. In this game each card represents a RM or an action toward the green energy transition and contains a short paragraph explaining to the players the main use of the element in the field of renewable energies or the advantages of technologies. The players act to remove the RMs from their opponent's supply, represented from the cards in their own decks, or to nullify the opponent's "life points" that represent the capability to work with RMs. In addition, "energy units" special cards have been inserted to strengthen the link with the technological value chain reality. In order to reinforce the learning, three question-times have been foreseen along the game on some scientific information reported in the cards. This mechanism fosters the motivation in reading the scientific texts because, if the answer is correct, a reward system for the player is activated and it makes it easier to win. The game has been tested in some non-formal learning settings and the feedback collected was very positive. In conclusion, this serious game is a very promising learning tool that can be used for fostering the acquisition of tackling awareness of the RM relevance in the transition to renewable energies in an enjoyable and self-explanatory way.

Keywords: *raw materials, gamification, energy transition, middle school, cross-curricular learning, serious game*

1. Introduction

1.1 Scientific Topic

There is a shared opinion that the transition to a more sustainable energy system is an urgent issue if we intend to keep the increase in global temperature below the threshold of 1.5 set by the 2015 Paris Agreement. To achieve this goal, it is essential to implement the renewable energy sector, electric cars, energy infrastructures and aim for energy efficiency [1]. However, these strategic value chains require the extraction and use of a large quantity of raw materials (RMs), many of which are at risk of supply to the European Union because it has not relevant mineral deposits of them, the recycling technology is not developed and there are few affordable supplier in the World: these are called critical RMs. The European Union works constantly to draw up an updated list of all critical RMs, divided by sector (for example, photovoltaic panels, batteries, electric cars, etc.) [1-2]. This fundamental aspect of the energy transition is not sufficiently disclosed to the public, whose greater awareness would be useful to promote more sustainable consumption styles, which consider the value of objects, as well as the reuse and recycling of materials.
Some learning paths for pupils from 10 to 18 years old have been developed in the framework of "Raw Matters Ambassadors at Schools" (RM@Schools), a European project funded by the European Institute for Innovation and Technology (EIT), the largest consortium in the RMs sector worldwide

(http://rmschools.eu/) to foster students' interest in RM-related sectors. Among the different educational approaches used in RM@Schools, the gamification one constantly showed to be very effective in different learning contexts [3-4]. Similarly, the game-based learning methodology has been particularly used in the national project "Change the Game: playing to be trained for the challenges of a sustainable society" (https://www.changegame.cnr.it/) which is linking official curricula developed at school with the European challenges of our society [5]. In fact, the game tool proves to be particularly useful in learning contexts, even formal ones, as it proposes scenarios and settings that often cannot be replicated, making use of the metaphor tool to promote the acquisition of content and the development of skills in an implicit way [6]. Precisely the fact of being a free choice makes the game so effective, since it leverages the intrinsic motivation of the subject, a characteristic which has been exploited by important figures of modern pedagogy.

1.2. Educational Methodology

In the common imagination, gaming is perceived as non-serious activity; in reality, it is only an appearance: the fact that it is separated from true reality and set in a fictional one does not mean at all that the player is not engaged in the recreational activity, on the contrary, since the game is an immersive experience it fully involves the subject on multiple levels, including the emotional one [7].
Learning therefore takes place in an active manner, as users are encouraged to interact with the game to progress and achieve the set objectives, without necessarily perceiving the process as a traditional moment of study. Compared to more traditional teaching methods, learning through games presents further important advantages: firstly, it allows the creation of a more relaxed and less rigid environment, in which each student-player is called to participate personally, developing thus those social skills necessary in comparison between peers, such as empathy, proactivity and respect for the rules shared with other players [8].
Games not only represent a tool to optimise learning, but also offer a new approach to the organisation of the learning process itself. The ideal approach is to combine entertainment and learning in a synergistic way, so that players do not perceive the learning phase as separate from the game itself [9]. This concept of "invisible learning" should guide the design, use and evaluation of games for educational purposes [10]. Recent studies indicate that the effective transmission of information on crucial issues such as sustainability, may depend more on the mode of communication than on the quantity of information transmitted. Games are emerging as powerful tools to raise awareness of important issues such as sustainability and the energy transition. Serious games are gaining popularity for their ability to stimulate, provide immediate feedback and adapt to the students' level, thus contributing to the transfer of knowledge and the use of various teaching techniques. In particular, educational games about sustainability and energy are becoming increasingly popular, especially in online versions, offering a wide range of engaging educational experiences [11].
On the basis of the literature and of our European and national experiences, we decided to develop an educational game for enhancing the awareness on RMs necessary for the energy transition, tailored mainly to an audience of young people and teenagers.

2. Raw Materials Fight: a Duel Card Game for Energy Transition

Here we present an educational card game titled "Raw Materials Fight", aiming to increase the awareness on the RMs role in the energy transition.
In order to develop the educational card game, two main steps were followed:
1. *Preparatory stage*. This includes content research and selection of the key terms from the selected topic to be understandable by the audience target, conceptualization and planning of the instructional material developed.
2. *Game development:* card design, game rules, pilot testing, and revision. Immersion in instructional content, playfulness, and peer interaction were among the top considerations in drafting the rules of the game.
The game, set in a fantasy scenario where the players have to complete the energy transition for winning, presents the main RMs in the renewable energy field, their application and some supply and energetic policies to reduce climate impact (**Table 1**). In the game, the two players have their own deck of cards and play one opposite to the other. Each deck is composed by 50 different cards, divided into four types represented by four distinct colours: the blue and green cards represent RMs divided in elements and compounds, respectively; the red ones are focused on some process and

actions related to the RM-value chains, and the purple ones represent some energy sources (i.e. see **Fig. 1** and **Fig. 2**).
Every card features a short paragraph that introduces the player to the main use of the element or compound in field of the renewable energies, or the advantages offered by some technologies and actions toward this energy transition (**Table 2**).

Table 1. List of the RMs present in the card game (blue and green cards)

Raw Materials used in the technology related to Renewable energies		
Aluminium (Al)	Borates (minerals containing Boron)	Cerium (Ce)
Cadmium (Cd)	Cobalt (Co)	Copper (Cu)
Dysprosium (Dy)	Fluorspar (CaF_2)	Gallium (Ga)
Germanium (Ge)	Gypsum (CaSO4·2H2O)	Helium (He)
Indium (In)	Iron (Fe)	Lead (Pb)
Limestone ($CaCO_3$)	Lithium (Li)	Magnesium (Mg)
Manganese (Mn)	Molybdenum (Mo)	Natural Graphite (C)
Neodymium (Nd)	Nickel (Ni)	Niobium (Nb)
Palladium (Pd)	Platinum (Pt)	Phosphorus (P)
Potash (K_2CO_3)	Praseodymium (Pr)	Rare Earth Elements (REEs)
Silica (SiO_2)	Silicon (Si)	Silver (Ag)
Tellurium (Te)	Tin (Sn)	Titanium (Ti)
Vanadium (V)	Zinc (Zn)	

During the match, the cards have different roles: the blue cards serve as "fighters," because they present the RM attack and defence points, and their chemical element is depicted by fantasy creatures to attract the attention of teenagers (**Fig. 1**). The attack and defence points are calculated on the basis of two real physical-chemistry properties of the elements and are the basis of the game mechanism. The green and red cards offer effects that empower the owner or weaken the opponent in various scenarios, whereas purple cards supply more energy points (EPs) during the game. To make the public aware that the energy transition needs an energy investment to be built up, each card also shows the energy cost needed to play it, as a metaphor of the energy spent to extract and refine the RM or to enact a policy.

Table 2. Some of the elements involved in wind energy technology present in the game and their description reported on the card.

Element name	Content description
Iron (Fe)	The fourth most abundant element in the Earth's crust*, it is of historical importance for humanity. It is the basic component of any type of steel and the most powerful magnets (NeFeB).
Niobium (Nb)	Element present in a small percentage to produce high-strength structural steel, suitable for the construction of the tower in wind turbines.
Aluminium (Al)	It is the third most widespread element in the Earth's crust*. It is used to produce particularly light alloys, for example to make wind turbine blades.
Neodymium (Nd)	This metal belongs to the group of rare earths, or lanthanides. Its main use is in the creation of permanent magnets, used in audio systems and wind turbines.

* By taking into account the oxides, iron oxides are the third component of the upper continental crust (5%), after $A_{l2}O_3$ (15%) and SiO_2(66%).

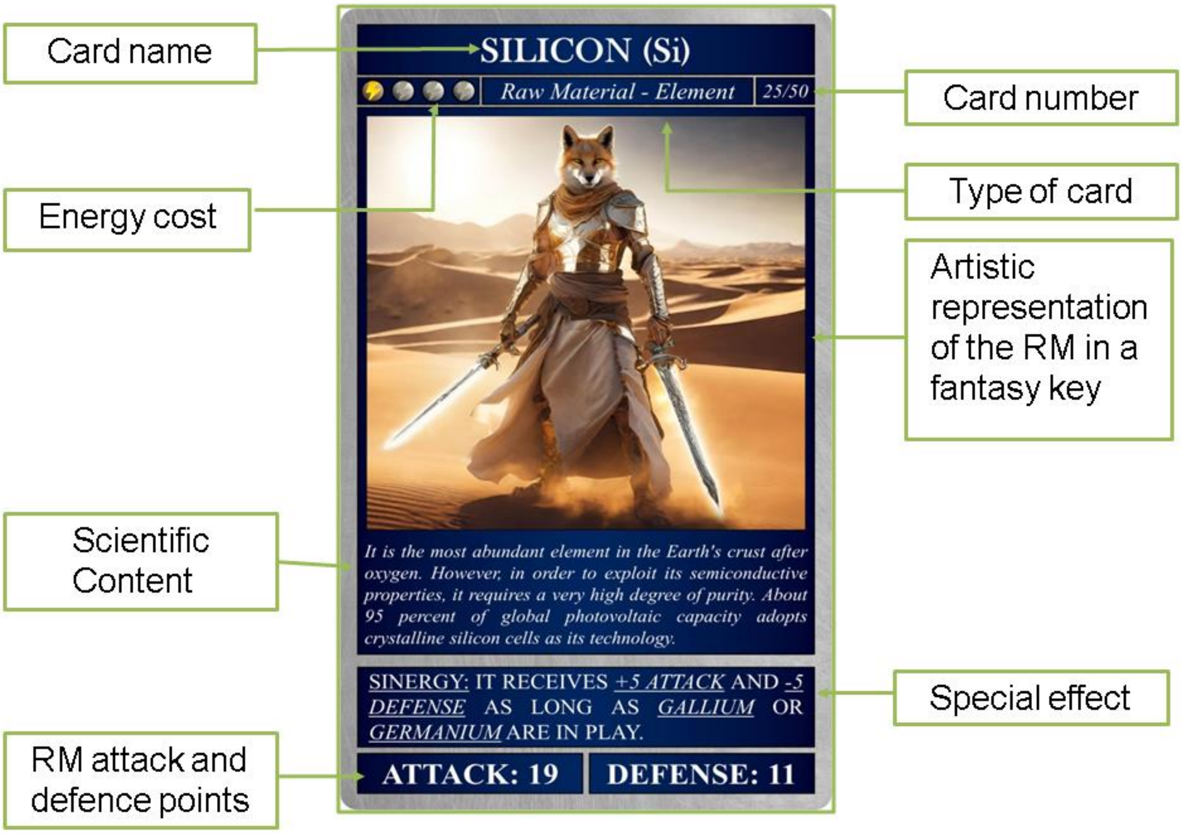

Figure 1: Example of a blue card.

The basic rules of the game are quite simple and are inspired by other duel card games (e.g. Yu-Gi-Oh!, Magic, Pokemon, etc.): two players duel each other using a variety of RMs, policy strategies, and energy sources cards to defeat their opponent's RMs and be the first to drop the other's Life Points (LPs) to 0.
Each player starts with the same number of LPs, that represents the capability to work with RMs. When a player takes damage, subtract that damage from their LP: the first one who reaches zero LPs loses the game. To inflict damage on the opponent, the player has to deploy RMs from their own deck.
In order to highlight the limited resources of the planet, we have created another eventuality that results in the player's defeat: when his deck of cards runs out. When a player plays a card, he must spend EPs or discard some cards from their own decks to play the cards, learning that the transition has a cost in terms of energy or RMs.
As regards to the game design, the card pictures were developed to be both eye-catching and informative about the features or applications of the items. Being a transposition in a fantasy key, each image is the result of a compromise between fantasy and scientific content. For example, in Fig.1 the Silicon element is a half-fox warrior in a sunny desert landscape, because this element is obtained from sand ore, and it is used to produce photovoltaic panels that are used in sunny regions.
In order to underline the importance of combination of different chemical elements in energetic technologies (e.g. Silicon, Gallium and Germanium in photovoltaic panels), some elements are mutually enhanced if present on the playing field at the same time.
Energy costs, instead, are not correlated with real energy expenditure, but only with the card power in the game. The reason for this choice is twofold: firstly, it is too complicated to estimate exactly the energy investment to extract and refine a single RM, or to develop a technology; secondly, the game needs to be well-balanced to make it fun and enjoyable. Furthermore, there are few cards that require a card cost, instead of energy, to be played, such as energy source cards: this is linked to the fact that some energy sources, such as fossil fuels, are not renewable and require an expenditure in terms of resources. It will be up to the player to choose if and when to use them, as excessive use of these cards, even if it could prove short-term advantageous, will probably lead to defeat. For chemical elements, attack and defence statistics were calculated based on electronegativity and atomic radius, respectively; for example, the Lead (Pb) card has one of the higher attacks in the game because of its relatively high electronegativity among the selected metals.

Figure 2. Three examples out of the four card types present in the game. From the left: red card (action in the framework of circular economy), green card (raw materials), purple card (energy source).

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Finally, to foster the motivation in reading the scientific information reported on every card because playing the game can distract from the learning content, when every player goes below the three thresholds 150, 100 and 50 LPs, it is possible to answer a scientific question and gain new LPs.
To find, mitigate, and eliminate potential issues, so as to reach a good quality in the prototype developed, some tests were implemented. In fact, testing is one of the critical processes accompanying the design and development of an educational game. The testing process was carried out by organising some focus groups which played a role, especially in the initial stage of game design. These focus groups consisted of meetings with CNR researchers and students providing feedback, likes, and dislikes on the upcoming game topic and allowed iterating on existing ideas more effectively. In addition, these groups were allowed to perform a simple Quality Assurance Testing aimed not to play and enjoy the game but to identify all the major problems and make sure the game meets all the predetermined requirements as well as check the educational contents.
A first prototype of the game, with simplified images, was used with success in informal settings, such as a mineral fair which offered the opportunities to the participants for learning beyond traditional or "formal" schooling (**Fig. 3**).The attendants were observed while playing the game and making some comments about their experience: the general feedback was positive. Great interest also came from a company that produces table top games for a potential commercialisation of the card game.
One of the risk of this game-based approach, is that players can be involved only by the entertainment element, and learning results to be too much superficial [12]. This tool can be very useful for boosting the interest and curiosity towards the RMs and energy transition, but is not sufficient for acquiring a deep knowledge of these topics. For the use in a classroom, the teacher should plan complementary activities such as a short lecture, opening discussion among students on the role of RMs in the energy transition, or encouraging them to find autonomously further information on RMs in the every-day life

devices. Moreover, it is to be taken into consideration when designing such games that teachers are concerned about the conventional curriculum and are also on a limited time schedule. Thus, this educational game can be easily integrated in the class program of citizenship education or in the shop class.

Figure 3. Testing session of first "Raw Materials Fight" prototype.

4. Conclusions

Serious games have huge potential as a means of improving achievements in a variety of domains including education. The game titled "Raw Materials Fight" can light-heartedly teach some information on chemical elements and compounds presenting the connection between some RMs and the technologies involved in the transition to the renewable energies needed to stop the emission of carbon dioxide and the consequent global warming. In the first test the game received very satisfactory feedback from its users, both in terms of enjoyment and learning. However, the game cannot be self-sufficient in a formal learning environment such as school. The teacher should think about a deepening of the RMs-related topics in continuity with what the game introduced. In fact, for the success of serious game, an important aspect for the game-designer is to achieve a balance between the fun element and the main purpose of the game that is the transfer of some knowledge. This means that the entertainment element of the game should not be sacrificed in the attempt to maximize the cultural aspect. It may be tempting to give priority to the serious element of the game over the engagement that the game is supposed to provide. However, the enjoyment of the game is the very means by which the goal can be reached, how this balance can be achieved is still an area open to the research.

Acknowledgements

This activity was developed in the project "Change the Game: play for preparing to the challenge of a sustainable society" (C.U.P. B53C22000750005) funded in the programme ResearchProjects@CNR (SAC.AD002.173.042) in the stream of the project "Raw Matters Ambassadors@Schools 4.0" (RM@Schools4.0) funded up to 2023 by the European Institute for Innovation and Technology (EIT) Raw Materials, project agreement no. 20069.

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