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Gamification of Bioeconomic Prey-Predator Model*

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In this paper we present educational game developed with major aim to educate and raise awareness of people about ecological issues in reserves of nature. In order to fulfil this aim, we decided to implement simulation game based on prey-predator model. Another part of the game are flesh cards, with questions and answers targeting specific problems and species in nature reserves. Case study given in this paper is Special nature reserve Uvac from Serbia. This is the only one reserve in Europe which is the habitat of griffon vulture, which is endangered species, very important for protection of nature, preventing expansion of various infectious diseases. Developed game shows what would happen if there is no enough prey population (carcass in the case of Uvac) and also when there is no enough predator population (griffon vulture in this case).

Keywords: gamification; prey-predator model; ecology; Special Reserve of Nature Uvac

1. Introduction

Special Reserves of Nature (SRN) are protected areas of ecological environment, for which governments define conditions and obligations through the law, in order to protect plant and animal species and other natural assets, such as land, water, air, cultural and historical values contained within the protected zone [1]. Due to the rarity of natural resources within the protected areas, there are permanent intentions of visitors and residents to degrade natural resources and values. We can identify two major groups of reasons for this degradation. First one occurs because of inattention of visitors or residents living nearby or within the protected area. Carelessness includes waste disposal, lighting fires, high density of visitors to the parts of protected areas, causing noise that harms species in protected wildlife areas, etc. The second group, consisting of intentional, usually economically motivated activities of visitors and of the population. These activities include the exploitation of forest mass, exploitation of plant and animal species, the illegal catch and hunting of wildlife, construction of facilities for a holiday in restricted areas, the discharge of untreated wastewater into watercourses, etc.

Raising level of ecological awareness and responsibility of residents and visitors of protected areas can have positive impact on both identified group of problems. Education directed at building positive attitude and gathering new knowledge about ecological problems can significantly raise responsibility for protecting natural environments. Economic incentives for raising awareness of the population to engage in the protection of Uvac area and other protected environments are in the potential benefits from the increase in the number of visitors and tourist services.

Eco-tourism is becoming increasingly popular in the form of tourist services which are connected with preserved natural values and the diversity of the environment that makes it a natural reserve. Eco-tourism is a form of tourism based on the specific offer based on the preservation of natural environments, which represents the natural "capital" of this kind of tourism. In developing environmental awareness through the development of tourism, it is important that we bear in mind the permitted level of capacity utilization. The point is that it is necessary to determine the daily, weekly, monthly and annual entry of visitors in protected areas.

A special problem for development of environmental responsibility and awareness about need to preserve the natural uniqueness and diversity of plant and animal species and the environment of the reserve is to influence actors that their personal economic benefits values far more than preservation of natural resources. Their economic benefits from deforestation, hunting and fishing, cost avoidance of investment in collection and removal of waste, avoiding investments in wastewater treatment, are valued more than social or external costs arising from their activities. On this plan government can act synchronized in two ways. Education and training can influence the younger generation, and legal repression and punishment to those members of the community who tend to minimize the environmental and wider social benefits that protected areas carry out in order to maximize their personal particular interests.

This paper presents developed educational game, based on simulation of prey-predator model developed with major aim to educate and raise awareness

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of people about ecological issues in reserves of nature. One of the major characteristics in biological ecosystems is that balance between prey and predator species have to be maintained. If this balance is disrupted, that will have negative consequences for both species, also for other related species and for the ecosystem as a whole. That's why is very important to save endangered species, even if they are predators.

Our first application of the game is for Special reserve of nature Uvac from Serbia. This is the only one reserve in Europe which is the habitat of griffon vulture, which is globally endangered species, very important for protection of nature, preventing expansion of various infectious diseases. Developed game shows what would happen if there is no enough prey population (carcass in the case of Uvac) and also when there is no enough predator population (griffon vulture in this case).

Another part of the game are flesh cards, with questions and answers targeting specific problems and species in reserves of nature. Cards created for initial version of the game are directly related to SRN Uvac.

This game is developed as a part of research project "*Economic aspects of costs and benefits of the environmental policy in the Republic of Serbia*". Major aim of the game is to raise awareness about preserving nature and importance of prey-predator balance in any ecosystem for sustainable development.

Chapter two presents literature review in the field of gamification in ecology. Before detail description of the game, we give theoretical basis for prey-predator models in chapter three. Prey-predator models belong to nonlinear complex systems. These models can be applied in modelling systems in different scientific areas, such as ecology, neural networks, traffic jams, evolution of biological systems, immunology, economy, financial markets, optimisation theory, etc.

2. Literature review

There are a lot of different definitions of gamification in literature. We would like to point out two of them. Lee and Hammer [3] defined gamification as "the incorporation of game elements into non-game settings", while Salen [4] defined gaming as " . . . the sum total of activities, literacies, knowledge, and practices activated in and around any instance of a game".

There are lot of research about importance of gamification in education, such as is paper of Bishop [5], Stott and Neustaedter [6], Jordan and Suthers [7], Lee and Hammer [3]. Salen states that the concept of playing and learning dating back as far as 1840, which is an example of educational institutions called "kindergarten" where is taught through the use of games and game [7]. Stott and Neustaedter [6] shows that use of gamification can be a powerful tool in guiding the process of teaching to positive learning effects. They concluded that gamification of the classroom can lead to increased student engagement and success.

Gamification in ecology is explored by Westelius [8]. Widawska-Stanisz [9] in their paper on the importance of gamification in marketing cites two examples of gamification in ecology. The first example of gamification may be to reward drivers for driving in the way of using less petrol (is used by the producer of Honda Inside). Another example that Widawska-Stanisz [9] provides is a web page which encourages Internet users to recycle different types of materials, in the same time urging them to buy some products and offering advertisers possibility to promote by some actions on the portal.

SRN Uvac has been founded as the area for protection of the population of the European Griffon Vulture (Gyps fulvous), one of the most massive species of ornitofauna in Serbia [10]. The griffon vulture is a scavenger bird, one of the more significant factors in the food chain and cleaning of nature through prevention of the spread of infectious diseases. Key natural resources of Uvac are: waters, land, woods, wildlife and fish. Flora of the Uvac preserve includes more than 500 species of plants, among which a large number of rare, endemic, medicinal or edible herbaceous and woody plants. There are well preserved fragments of high stands of beech, spruce and fir tree [1, 2].

Lotka—Volterra model (LVM) is one of the oldest prey-predator models, based on mathematical principles [11, 12]. LVM is widely used as a basis for development of many models used today for population dynamic analysis [13]. It's usual to represent LVM in continual-time, but we will present also discrete-time version, as in [14]. Authors analysed two-dimensional LVM with five parameters, adapted by a non-monotonic response function [15].

Doyen with co-authors developed a bio-economic model [16]. They identified fishing strategies that satisfy both ecological conservation and economic sustainability in a multi-species, multi-fleet context. They showed using Stochastic simulations how Co-Viability Analysis can guarantee both ecological (stock) and economic (profit) sustainability. Another one research team examined the viability of a fishery with respect to economic, social and biological constraints [17]. Their main constraint (economic constraint) is a minimum profit per vessel that must be guaranteed at each time period. They showed that requiring such a minimum profit induces a minimum threshold for the natural resource, and thus a stronger constraint on the resource stock than the initial biological constraint. Their biological constraints are based on the definition of a minimum resource stock to be preserved. Their social constraints refer to the maintenance of a minimum size of the fleet, and to the maximum speed at which fleet adjustment can take place [17]. Authors in [18] investigate the effects of harvesting on the dynamics of the prey–predator system. Moreover, they discusses a class of hybrid biological economic models, where the dynamics of prey population is governed by differential equations, predator population is governed by difference equations and economic theory by algebraic equations. Their model indicates that economic profit may bring impulse at some critical value, i.e., rapid expansion of biological population in terms of ecological implications. On the other side, their model shows that the increase of economic profit destabilizes the system and generates a unique closed invariant curve. These authors showed that when the economic profit increased the density of population would expand rapidly, which induced ecosystem unbalance and even biological disaster [18]. However, they concludes that applying the state feedback control method, which can be implemented by adjusting the harvesting costs and the economic profit, impulsive phenomenon will be eliminated and biological population can be controlled at steady states. Some authors proposed a biological economic model based on prey-predator dynamics [19]. They have discussed the behaviour of the model system with positive economic profit. In case of without time delay they observed that though the model system is stable but it is possible to get a critical value of total economic profit so that the model system becomes unstable when total economic profit passes through the critical value and the model system enters into Hopf type small amplitude periodic solution. They noted that continuous time delay also plays an important role to the dynamics of the model system. Their results suggest that the time delay can cause a stable equilibrium to become unstable and even a simple Hopf bifurcation occurs when the time delay passes through its critical value [19]. Çelik considered a ratio dependent predator-prey system with time delay [20]. He considers the time delay as bifurcation parameter, and he analysed the stability and the Hopf bifurcation of the system. He concluded that the stability properties of the system could switch with the time delay that is incorporated on different densities in the model. De Lara and Martinet addressed multi-criteria decision making under uncertainty, as a way to tackle sustainable management issues for bio economic systems [21]. The sustainability of this system is described by a set of constraints. They have developed a viability analysis based on the definition of a set of constraints that represents the various sustainability objectives. They propose to rank management strategies by the probability that the resulting intertemporal trajectory satisfies all of the objectives over the planning horizon. They found that an optimal management rule is one that results in the highest viability probability [21].

3. Prey-predator system: theory

3.1 Continuous two-dimensional model

In this chapter, we will consider biological application that was developed independently of each other by an American physical chemistry Lotka and the Italian mathematician Volterra [22]. Volterra tried to explain the observation of oscillatory fish catches in the Adriatic Sea with the set of two ordinary differential equations; the first for prey population, the second for the predator concentration [12]. While Lotka developed the same approach for a system of chemical species [11, 23]. Murray noticed that Volterra was the first who applied the Lotka-Volterra system to an ecological problem [24].

Dynamic between pray population and predator population is modelled with differential equations:

$$\begin{aligned} \dot{x} &= ax - bxy, \\ \dot{y} &= -cy + dxy, \end{aligned} \tag{3.1}$$

where *a, b, c, d,* are positive control parameters [25].

Meaning of members of equation system (2.1) [13, 22]:

- *ax*—the growth rate of prey populations in the absence of predators. In the absence of predators, prey population grows exponentially according to the equation.
- *bxy*—rate of extinction of prey populations due to attack of predators.
- *cy*—rate of extinction of predator populations due to lack of food. In the absence of prey, predator populations are dying (decreasing) following the exponential equation.
- *dxy*—offspring birth-rate for predator population, which is directly linked to eaten number of prey population.

The rate of change of each population can be viewed if we divide each of equations with number of members of the population:

$$\begin{aligned} R_x &= \frac{dx}{xdt} = a - by, \\ R_y &= \frac{dy}{ydt} = dx - c, \end{aligned} \tag{3.2}$$

where R_x is the relative rate of change in prey populations, and R_y relative rate of change in predator populations. Variables R_x and R_y are known as a function of the prey and predator populations respectively [22].

It is important to emphasize that without interaction between prey and predator populations, prey population would grow exponentially with the rate R_x, while the predator population would decrease exponentially with the rate R_y. However, it is assumed that for behaviour of the system as a whole, this interaction is crucial. Prey consumption and predator population growth, both increase or decrease with x and y, which is expressed by the two terms including the product xy [23].

Unfortunately, in its original form Lotka-Volterra model has several significant problems [13]. One of them is that it does not take into account competition between prey and predator populations. As a result, prey populations can grow indefinitely without any limitation on resources. Predator populations have no saturation; their level of consumption of prey populations is unlimited. The level of consumed prey is proportional to their population density. It is therefore not surprising that none of the equilibrium point of the system is not asymptotically stable [26]. Another deficiency is that the predator and prey populations are changing in a constant cycle without stopping. It can be shown that it will behave like this for any set of values for the four parameters of the model. Although this movement was observed in nature it is not common. It follows that the Lotka-Volterra model is not sufficient to model many predator-prey systems but has to be worked up for specific cases. Thus, this model is not very realistic [13].

3.2 Discrete prey-predator model

Authors of [14] mark with $N_i(t)$ the abundance (the number of individuals as an approximation of the continuous real number) or the density (the number of individuals per unit area) of species $i \in \{1, \ldots, n\}$ at the beginning of time span $[t, t + 1)$. Dynamics of ecosystem and interaction between species are given by Lotka-Volterra model:

$$N_i(t+1) = N_i(t)\left(R_i + \sum_{j=1}^{n} S_{ij}N_j(t)\right) \tag{3.3}$$

- Prey populations grow in the absence of predators (those species i for which is $R_i \geq 1$, while predators die in the absence of prey (when $R_i < 1$).
- Effect i and j is given as member S_{ij} so that i consume j when $S_{ij} > 0$ and i is the victim (prey) of j if $S_{ij} < 0$. Numeric answer of consumer depends on the number of victims per unit of time (functional response) and the efficiency with which the captured preys are concentrated into offspring. In this model, we will present the effect of j prey on consumer i where $S_{ij} = -e_{ij}S_{ji}$, where e_{ij} is conversion efficiency ($e < 1$ when the size of consumers is greater than the size of prey).

The strength of direct specific interaction is given by $S_{ii} < 0$. Possible mechanisms behind such self-limitation are the mutual interference and competition for non-food resources.

They emphasize that the ecosystem is also the object of human exploitation [14]. Such anthropogenic pressure induced harvests and catches $h(t) = h_1(t), \ldots, h_n(t)$ modifies the dynamics of the ecosystem according to the equation:

$$N_i(t+1) = (N_i(t) - h_i(t))\left(R_i + \sum_{j=1}^{n} S_{ij}(N_j(t) - h_j(t))\right) \tag{3.4}$$

By condition that the number of capture does not exceed the value of inventories $0 \leq h_i(t) \leq N_i(t)$.

Authors pointed out that species competition is an issue of fundamental importance to ecology [14]. For this purpose, we used the Lotka-Volterra competition model from the classical theory.

Tilman has introduced a new model of competition between species, which is based on mechanical resources [27]. He used the requirements for resources of competing species to predict the outcome of the competition among the species. The strength of this model based on resources (the resource-based model) lies in the principle of exclusion. This principle says that, in the context of competition of more species for some limiting resources, types with lowest demand for resources in a competitive equilibrium will displace all other species. In this setting, the system must be a monoculture and the equilibrium outcome of competition is actually a kind of survival of the species, which is a superior competitor for a limited resource, i.e., the type with the lowest resource requirement. This model is examined from the perspective of bioeconomy in order to manage renewable resources [14].

Lorenz discovered an entirely new behaviour of non-linear systems that was not known before. This behaviour is reflected in the fact that the trajectories do not converge to a stable equilibrium state nor oscillate towards infinity. Within a limited region, trajectories show chaotic behaviour. This phase space is also known as the system called Lorenz's attractor [28].

Holzbecher claim that even simple non-linear systems may exhibit chaotic behaviour [23]. Also, systems of chemical and biological species may lead to similar observations as Lorenz's system. Devaney states that if the model is a chaotic system, then it cannot be used for prediction. In fact, the chaos in the above sense can be characterized that a minor deviations in the initial state leads to significant deviation in the final states. Therefore, it should be borne in mind that dynamic systems can exhibit such "strange" behaviour [23].

4. Game developed

Special reserve of nature Uvac was established as an area for the protection of the population of griffon vulture (Gyps fulvus), which is one of the largest representatives of ornithofauna in Serbia. Griffon vulture is a scavenger bird that is one of the essential factors in the food chain and cleaning of nature by preventing the spread of infectious [2, 10, 29]. Authors of [30] analysed data on financial management analysis for the three Special Nature Reserve (SNR) in Serbia Zasavica, Uvac and Stari Begej—Carska Bara.

Conclusion of abovementioned paper was that there is an urgent need to raise awareness of residents and tourists about importance of preserving nature and to keep eco-systems in balance. In order to achieve this aim, we decided to apply gamification approach. In order to affect attitude of people about SRN Uvac, and to raise their awareness about importance of preserving nature, we have to constantly interact with them. Since most of the population have smart phones, developing mobile application was a natural choice. Android platform is widely used in Serbia, and it's chosen as a target platform for our application. Figure 1 shows welcome screen and pray-predator simulation screen.

Providing users with a prey-predator simulator, but in context of SRN Uvac, will enable them to see what would happen if balance between prey and predator species is interrupted. If this balance is disrupted, that will have negative consequences for both species, also for other related species and for the ecosystem as a whole. That's why is very important to save endangered species, even if they are predators.

Simulator is simplified in order to be easy for use on mobile phone, and for novice users, and it shows what would happen if there is no enough prey population (carcass in the case of Uvac) and also when there is no enough predator population (griffon vulture in this case). We found data in reference [2] that there are about 115 nesting pairs. Estimated number of griffon vulture in SRN Uvac is between 400 and 450 individuals. Since initial parameters for simulation are chosen randomly, each run would produce different outcome, enabling users to see development of different scenarios.

Another part of the game are flesh cards, with questions and answers targeting specific problems and species in reserves of nature. Cards created for initial version of the game are directly related to SRN Uvac. Figure 2 shows welcome screen and short tutorial screen, before game begin.

Fig. 1. Home and prey-predator simulation screen of application.

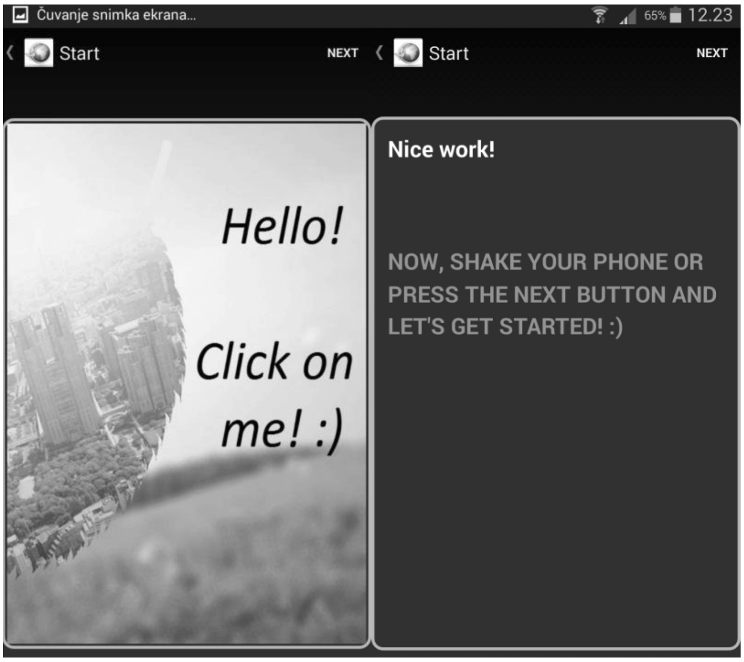

Fig. 2. Welcome and short tutorial screen for flash cards.

With one tap on the screen, card is turned on the other side, with animated effect. Usually, one side of the card presents picture, related to the content of the back side. Our idea is to support different kind of flash cards, such as: question/answer, concept/description, question/quiz, number/graphs, text/simulation, etc. In initial version of the game, we implemented simpler ones.

User can just shake his phone, and next card will be shown. Figures 3 and 4 present some of the cards. Since they are targeting local population, Serbian language is used.

While user is shaking phone and opening flash cards, game calculate his eco-awareness score, and visualise it as a N of 5 leafs. More green leafs mean higher eco-awareness score. Later, users can compare their score, and that could motivate them to consume more of cards. Eco-awareness score follow

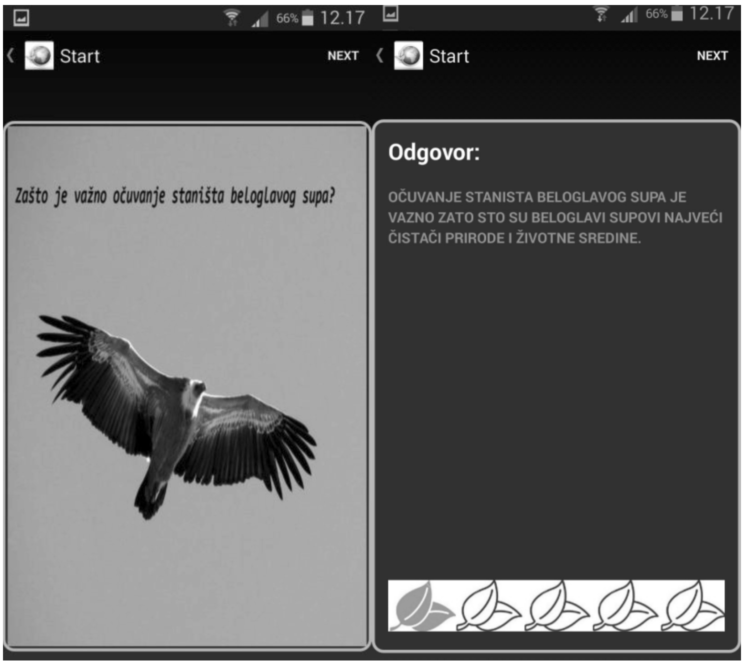

Fig. 3. Sample flash cards, question/answer type, about griffon vulture (Serbian language).

Fig. 4. Sample flash cards, question/answer type, about SRN Uvac (Serbian language).

high-score pattern from video games, proved to be very good motivating factor for players.

Game is developed as a stand-alone application, and users can consume it individually, on their mobile phone, without Internet connection. In the future, we plan to convert it into networked application, in order to enable users to exchange their eco-awareness scores through the application. We also plan to support more types of flash cards, and to provide flash card editor, which will enable each user to contribute with new cards to the community. All members of one community (SRN Uvac, for example) will have opportunity to consume new cards and to evaluate them, ranking it on scale from one to five. This will further improve interaction with users and engage them as an active community member would make them even more motivated.

5. Conclusion

In this paper we presented developed game, where we applied some of gamification principles, in order to educate people, as well as to raise their awareness, about ecological issues in special reserves of nature. Results of study conducted on the field of SRN Uvac shows clearly that there is a need for this kind of games. The game is consisted of two major parts. First one is simplified and visualised pray-predator simulation. Major aim of this part of the game is to show what would happen if there is no enough prey population (carcass in the case of Uvac) and also when there is no enough predator population (griffon vulture in this case).

Second part of the game is based on flash card model, where game support different kind of flash cards (such as question/answer, concept/description, question/quiz, etc). Cards are organized thematically, according to targeting areas of nature (SRN Uvac, for example). When user chooses his area of interest, he can just shake his phone, and new card will emerge randomly. When user taps on the card, it will turn on the other side, with animation, and show content on the back.

We also introduced eco-awareness score, based on high-score approach in games. It's shown on the back of each card, as five leafs. Initially, leafs are without colour, and as score is growing, more leafs are coloured in green. This way, users are motivated more to consume cards, and also to compare their score with others. Initially, we created flash cards for SRN Uvac, in Serbian language. This is the only one reserve in Europe which is the habitat of griffon vulture, which is endangered species, very important for protection of nature, preventing expansion of various infectious diseases.

For now this is a single-user game. We plan to convert it into a kind of social network, in order to enable users to exchange their experience and eco-awareness scores more easily. We also plan to support more types of flash cards, and to enable contributions of new cards from any user to the community. All members of one community (SRN Uvac, for example) will have opportunity to consume and evaluate them, ranking it on scale from one to five. Our expectation is that with this approach we could further improve interaction with users and their engagement and motivation, and consequently their awareness of ecological issues in special reserves of nature, or nature at all.

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