Revista Brasileira de Informática na Educação – RBIE
Brazilian Journal of Computers in Education
(ISSN online: 2317-6121; print: 1414-5685)
http://br-ie.org/pub/index.php/rbie

Submission: 05/Aug/2018; 1st round notif.:07/Nov/2018; New version: 19/Dec/2018; 2nd round notif.: 08/Apr/2019
Camera ready: 10/July/2019; Edition review: 10/Ago/2019; Available online: 01/Sept/2019; Published:01/Sept/2019

# Assessment of the prototype of an educational game on climate change and its effects on marine and coastal ecosystems

*Fernanda Miyuki Yamada*
*Federal University of ABC*
*fernanda.yamada@aluno.ufabc.edu.br*

*Thaís Ribeiro*
*Ferderal University of ABC*
*thais.ribeiro@aluno.ufabc.edu.br*

*Natalia Pirani Ghilardi-Lopes*
*Federal University of ABC*
*natalia.lopes@ufabc.edu.br*

## Abstract

*Climate change education is fundamental in the present society, which is characterized as complex and full of uncertainties. The use of games can help in this task. The prototype of an educational game called "Apicum Game", which addresses climate change and its effects on marine and coastal ecosystems, was assessed in the present study. Thirty-three students in the sixth grade of a private school played the game and answered questionnaires before and after it. The students who participated in the research generally play video games for fun. Also, they have already heard about climate change, mainly in television and school. It was possible to notice that the majority of students understood the concept of coastal ecosystems, which was addressed in the game. In addition, the game contributed to broadening the conceptual profile of students in relation to the complex concept of climate change. Finally, the game contributed to an increase in the number of actions cited by the students to mitigate climate change. The auto-assessment of the students indicated they learned from the game and that the educational content and challenges presented along the story were appreciated by them. Most of the students would play again or indicate the game to a friend. However, the graphics and some bugs must be improved/fixed so as to make the game more enjoyable.*

***Keywords:*** *educational software, Apicum Game, climate change education, coastal ecosystem.*

## Resumo

*A educação para as mudanças climáticas é fundamental na sociedade atual, caracterizada como complexa e cheia de incertezas. O uso de jogos pode ajudar nessa tarefa. O protótipo de um jogo educativo chamado "Apicum Game", que aborda as mudanças climáticas e seus efeitos nos ecossistemas marinhos e costeiros, foi avaliado no presente estudo. Trinta e três alunos da sexta série de uma escola particular jogaram o jogo e responderam a questionários antes e depois. Os alunos que participaram da pesquisa geralmente jogam videogame por diversão. Além disso, eles já ouviram falar sobre mudanças climáticas, principalmente na televisão e na escola. Foi possível perceber que a maioria dos estudantes entendeu o conceito de ecossistema costeiro, abordado no jogo. Além disso, o jogo contribuiu para ampliar o perfil conceitual dos alunos em relação ao conceito complexo de mudança climática. Por fim, o jogo contribuiu para o aumento do número de ações citadas pelos alunos para mitigar as mudanças climáticas. A autoavaliação dos alunos indicou que eles aprenderam com o jogo e que o conteúdo educacional e os desafios apresentados ao longo da história foram apreciados por eles. A maioria dos alunos jogaria novamente ou indicaria o jogo para um amigo. No entanto, os gráficos e alguns bugs devem ser aprimorados / corrigidos para tornar o jogo mais agradável.*

***Palavras-chave:*** *software educacional, Apicum Game, educação sobre mudanças climáticas, ecossistema costeiro.*

*Cite as: Yamada, F. M., Ribeiro, T., & Ghilardi-Lopes, N.P. (2019). Assessment of the prototype of an educational game on climate change and its effects on marine and coastal ecosystems (Avaliação de protótipo de jogo educativo sobre mudanças climáticas e seus efeitos nos ambientes marinhos e costeiros). Brazilian Journal of Computers in Education (Revista Brasileira de Informática na Educação - RBIE), 27(3), 01-31. DOI: 10.5753/RBIE.2019.27.03.01*

# 1 Introduction

The teaching of socio-environmental issues of the risk society (Beck,1997) require a treatment capable of incorporating and dealing with the complexity of the systems and their uncertainties (Morin & Lisboa, 2007). Thus, there is a need to debate these issues and incorporate them into citizens' discourses through an education inserted in the reflective perspective (Jacobi, Monteiro, & Fernandes, 2009; Beck, 1997, 2011).

Jacobi (2005) points to the need for a change in the fragmented structure of knowledge, which is generally replicated in schools, through a critical and political approach. The school, in this context, can be configured as the sphere responsible for making the link between socio-environmental problems and scientific explanations, which presupposes the view on the complexity (Watanabe-Caramello & Strieder, 2011).

Improvement of the environmental education process requires developing and practicing alternative pedagogical methods (Riordan & Klein, 2010). In this sense, certain alternative strategies could be interesting, such as "Phenomenon Based Education" or "Theme/Event Centered Education", in which the educative process is related to the dealing with real-world situations, which constitute the starting point for learning, focusing on problem solving and interdisciplinary approaches (Delizoicov et al., 2002; García, 1998; Cruz, 2001; Østergaard et al., 2010). These strategies prioritize teamwork, decision-making, student participation in the search for knowledge, a greater teacher-student relationship, didactic transposition, interdisciplinarity and conciliation of the knowledge seen in the classroom with the daily life of the student.

The teaching of climate change as a phenomenon throughout formal education systems can be one of the most important and effective means of developing capacities for addressing the climate crisis (Stevenson, Nicholls, & Whitehouse, 2017). Climate change education cannot be confined to traditional structures and formal curriculum spaces of education but needs to draw on new informal and hybrid (e.g. school/community) spaces offering alternative possibilities for learning and action.

Games can be an interesting alternative to traditional methodologies for climate change teaching and learning. Widely discussed in the literature, games have proved to be powerful allies in the educational process, as can be seen in the National Curricular Parameters in Brazil (known as PCNs - Parâmetros Curriculares Nacionais) (Brasil, 2000). Thus, if we consider subjects that require a closer approach to everyday life, such as environmental education, which is interdisciplinary and action-oriented, games can be very effective as a teaching tool.

Although there are many initiatives to insert the games as an educational tool, it is not possible to say that all the subjects of the curriculum can be covered by this technology. When it comes to climate change, there is a shortage in the supply of games. When we think about the influences of climate change on marine and coastal environments, this number is even smaller. This is

worrisome if we think that several consequences of climate change will affect marine and coastal ecosystems, through sea level rise, water acidification, rise in sea surface temperature, alterations in the water motion (tides and currents) or increase in the frequency of extreme events (storms and hurricanes) (Hoegh-Guldberg & Bruno, 2010). Also, these alterations will affect the marine and coastal biodiversity (Harley et al., 2006), causing, for example, coral bleaching or the migration of species.

In this context, the "Apicum Game" comes to light, proposing practical situations and inviting the student to discover through the scientific method the importance of preserving marine and coastal environments and how climate change impacts these ecosystems, and especially how it affects society. The game has the RPG style and was developed from a solid pedagogical base (Ghilardi-Lopes et al., 2013). The game takes place in a fictional coastal town called Apicum, which is presenting some strange circumstances, such as high rainfall intensities and high temperatures. According to the main character's teacher, local coastal ecosystems are also suffering from these climatic anomalies. Thus, the main character (the player) will have the task of investigating the causes of these climatic phenomena in the city and the coral reef near the coast of Apicum. The game is constituted of nine phases, in which the player will earn points of "environment", "society" or "economy", the three pillars of sustainability (Ghilardi-Lopes et al., 2015).

Besides being fun and attractive, games as an education tool must convey knowledge. That is why it is extremely important to think of methods for evaluating its effectiveness (Oliveira et al., 2015). Such evaluations should serve as a guide to identify possible failures and to enable the improvement of technology. Therefore, it is possible to set goals so that the expected objectives can be achieved and the educator can transmit the proposed content in a playful way without losing the teaching quality.

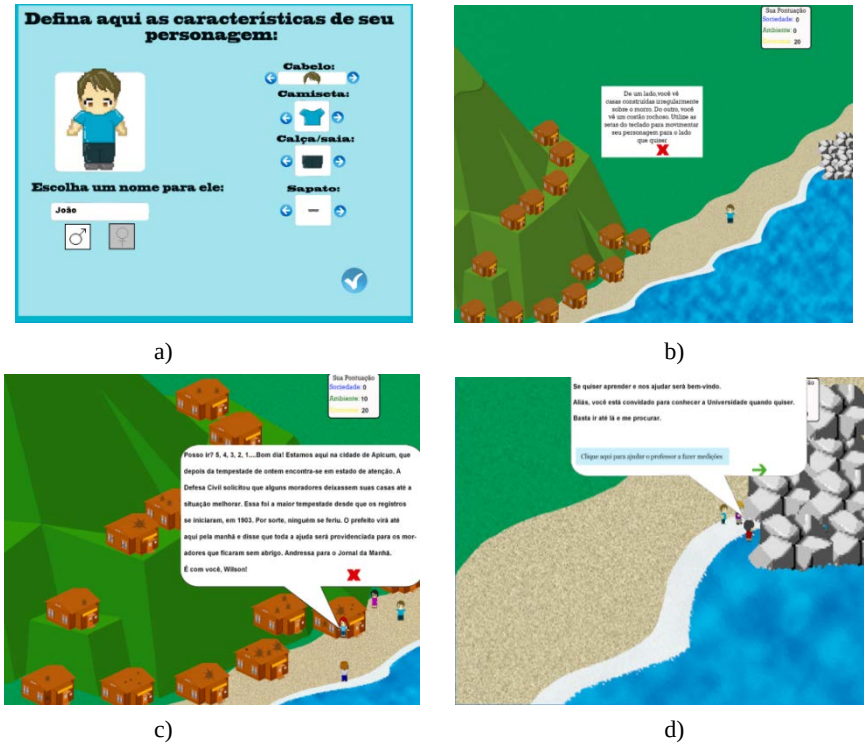
Taking this context into account, our work aimed to evaluate the application of the prototype of a serious game (titled "Apicum Game"), which aims to address the issue of climate change and its influence on coastal and marine ecosystems. In addition to understanding what, how and when students play, we addressed the educative potential of "Apicum Game", specifically how the game contributed to: 1) the learning of "coastal ecosystems" and "climate change" concepts and 2) the actions students can take to mitigate climate change. Also, we evaluated the feedback given by the students regarding the game itself (its weaknesses and positive aspects).

## 2 Apicum Game

The Apicum game is compatible with Windows Operating System, and can be downloaded HERE. Also, at this link, the online version of the pre-test and the post-test questionnaires are

available, so that anyone who plays the prototype of the game can contribute to its improvement. In order to install the game, the user must accept the terms of the Game Maker software.

Before the game starts, the player will be able to customize the main character, choosing the gender, hair color, and clothes (Figure 1a). After finishing the main character customization, the first stage of the game is presented to the player, in which the main character will be on the beach of Apicum city, and will have two options (Figure 1b): 1) go left, and see some illegal houses damaged by a storm, talk to a local resident and help some people to go to a shelter (Figure 1c); 2) or go to the right, and meet scientists working on a rocky shore and have the opportunity to assist scientists in their research (Figure 1d). In order to advance to the next stage of the game, the player has to complete both of the tasks proposed by the two possibilities of interaction.

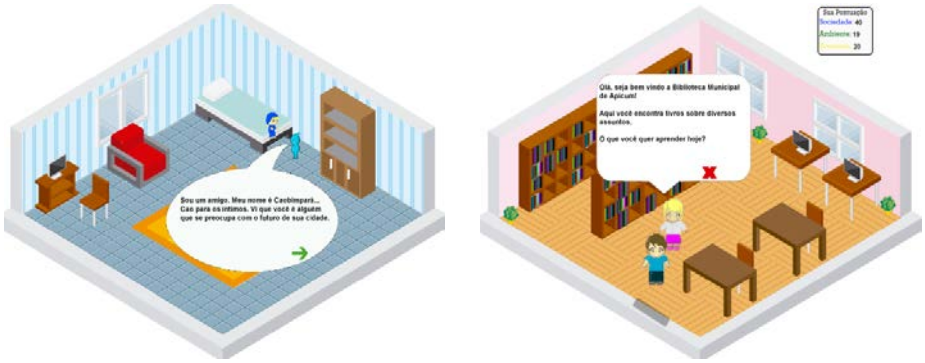



a) b)

c) d)

Figure 1: a) Customization of the main character; b) Beach of Apicum city; c) Houses damaged by a storm on the left side of the beach; d) Scientists working on a rocky shore on the right side of the beach.

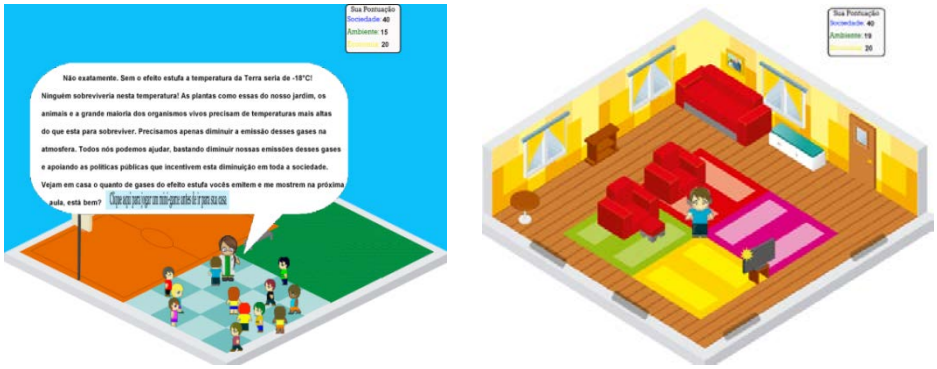
Then, the character will go home, where he/she will meet the character Caobimpará, who will encourage the main character to investigate what is happening in the city (Figure 2a). At this moment, the game map is presented to the player, in which the stages of the game are showed, and it is possible to distinguish the unlocked stages and the unlockable stages. In addition, throughout the game story, there is a stage that will always be unlocked, which is the library stage, where the player will be able to learn about some issues addressed in the game by clicking on the books on the shelves (Figure 2b).




a) b)

Figure 2: a) First appearance of Caobimpará; b) Library of Apicum city.

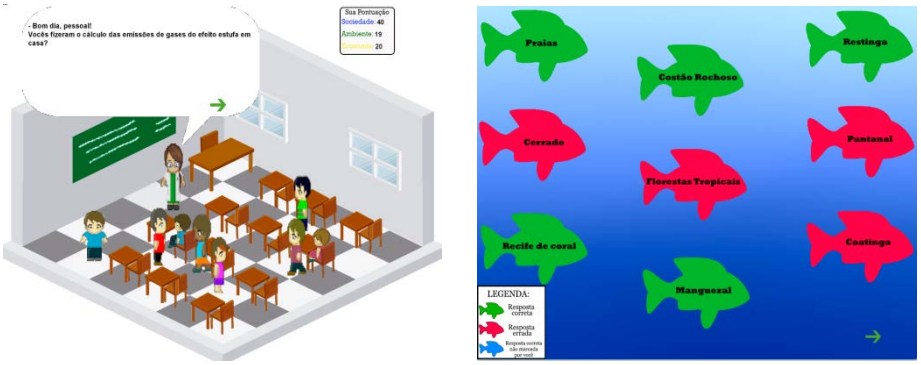
At this point, the main character will be sent to school, where the teacher will talk about global climate change and will ask some questions about this issue (Figure 3a). Then, the teacher will ask the students to measure their greenhouse gas emissions as homework. In order to complete this task, the main character will return to his/her house, and explore the house looking for electrical devices that represent sources of greenhouse gases (Figure 3b). After that, the main character returns to school, where he/she will compare his/her results with the average greenhouse gases emissions (which is approximately 1.8 tons a year for a single person) (Ghilardi-Lopes et al., 2015).




a) b)

Figure 3: a) Teacher talking about global climate change; b) Living room of the main character's house.

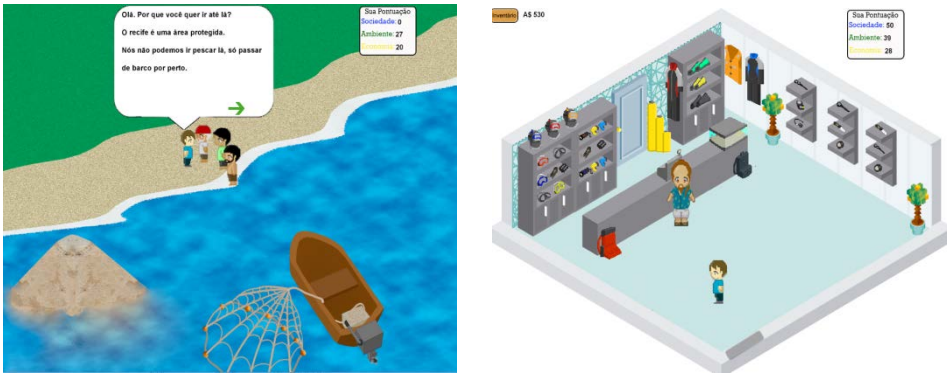
After comparing the results, the teacher will talk about the emissions of greenhouse gases and their consequences for the environment (Figure 4a). In addition, the player will learn about marine and coastal ecosystems (Figure 4b).




a) b)

Figure 4: a) Teacher talking about the emission of greenhouse gases; b) Minigame concerning marine ecosystems.

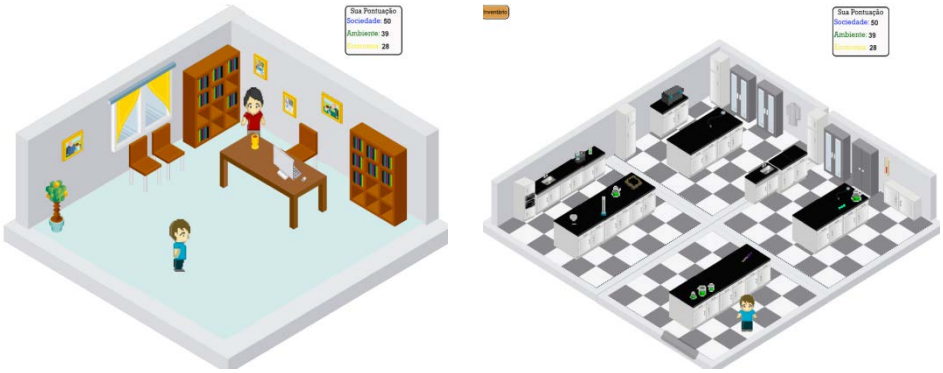
After that, the player will go to the beach in order to talk to fishermen and ask for a boat ride to the coral reef to study the effects of the climate change in marine ecosystems (Figure 5a). The fishermen will explain that it is necessary to know some scuba diving techniques, and that the character will need to acquire some equipment. To earn money, the player can help the fishermen with their work. After earning the necessary amount of money, the main character will be able to proceed to the store, where he/she will be able to buy the equipment required by the fishermen (Figure 5b).




a) b)

Figure 5: a) The main character talking with the fishermen; b) The main character buying scuba diving equipment at the store.

Next, the main character will go to the university to talk to a scientist, formulate hypotheses, and will be directed to get some equipment at the laboratory in order to check the condition of the coral reef during the scuba diving (Figure 6a). In the laboratory, the main character will be able to find a thermometer, pH meter, turbidimeter, oximeter, nutrient meter and a sampling unit (Figure 6b). With the equipment in hand, the main character will be able to take environmental measures on the coral reef and conclude how climate change is affecting this environment.



a) b)

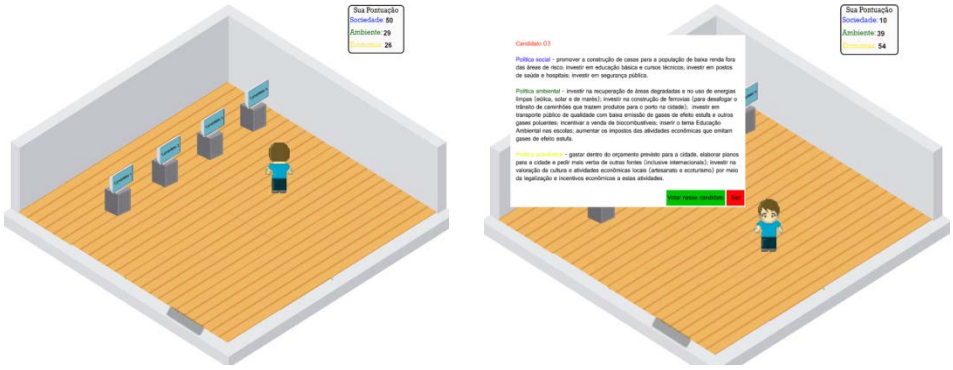
Figure 6: a) The main character meeting the scientist at the university; b) The main character gathering the equipment at the laboratory.

Also, during the scuba diving, the character meets Caobimpará again who will talk about the coral bleaching (Figure 7a). The main character will be able to use the acquired equipment to take some environmental measures (Figure 7b) and return to the university to report the obtained results to the scientist.


a) b)

Figure 7: a) The main character meeting Caobimpará in the scuba diving; b) The main character using the equipment to take environmental measures.

After talking to the scientist, the main character will go to the city hall, where he/she will be able to simulate an election by choosing among candidates with different proposals on "environment", "society" and "economy", and in doing so, the player will gain points in these three dimensions (Figures 8a and 8b). The goal of this stage is to show the player that there is a relationship between our choices and what happens to the environment, society and economy.



a) b)

Figure 8: a) The main character at the city hall to simulate an election; b) The proposals of one of the candidates.

Finally, the player will return to school in order to present his/her results to the teacher (Figure 9a). At the end of the game, the sustainability index of the main character is calculated, and the idea is that the player that presents the most balanced points in the three dimensions of sustainability was most successful in the choices made during the game aiming to mitigate climate change (Figure 9b).


a) b)

Figure 9: a) The sustainability index calculation; b) The final result based on the choices made during the game.

## 3 Basic Concepts

In this section, we introduce the basic concepts that based the development of the “Apicum Game”, which include: (1) climate change, (2) sustainability and (3) environmental education.

The concept of climate change is directly related to the “Apicum Game”, since the game addresses how global environmental change affects coastal and marine ecosystems. Climate change is defined as a change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties and persists for an extended period, typically decades or longer (Field et al., 2012). Scientific evidences indicate that human activity is causing global warming through the emission of greenhouse gases (Stern, 2008). Also, studies show that such

warming will only be slowed down or reduced if people around the world behave differently (Urry, 2015). Effective action will require international collaboration and some of the greatest impacts will be felt in the poorest countries that are most vulnerable to the changes (Stern, 2008). Climate change has been considered one of the nine planetary boundaries, which can be defined as the biophysical limits inherent to the functioning of Earth to maintain a stable state of systems condition for global sustainability and human welfare (Rockström et al., 2009a, 2009b; Steffen et al., 2015). The existence of such boundaries implicates in a new concept of sustainability, in which economy serves the society, which in turn is limited by an environmental "ceiling" (Raworth, 2012).

In the "Apicum Game", the concept of sustainability is worked. During the game, the main character earns points of "economy", "environment" and "society" (i.e. the three dimensions of sustainability) (Canotilho, 2010; Hansmann, Mieg, & Frischknecht, 2012) and, at the end of the game, his/her "Sustainability index" is calculated, in order to stimulate students to reflect on their attitudes and values regarding sustainability. The concept of sustainability is integrative and involves the protection of the environment and natural resources as well as social and economic welfare to the present and subsequent generations (Hansmann, Mieg, & Frischknecht, 2012). In this context, impacts of humankind on the Earth and ecological systems in terms of climate change, resource depletion and extinction of species revealed to us that sustainable development should be an essential part of human concerns (Kahriman-Ozturk, Olgan, & Guler, 2012).

Finally, in order to understand the context in which the "Apicum Game" was proposed, it is necessary to understand the current scenario of environmental educational initiatives and the main challenges of this research area. The aim of environmental education actions is that people become aware of the global reality, of the kind of relationships humankind establishes with nature, and of the issues derived from this relationship (Ghilardi-Lopes et al., 2013). It aims to increase awareness of environmental problems, motivate action through awareness, and develop a commitment to solve and prevent local and global problems (Jose, Patrick, & Moseley, 2017). In the 1960s, the "environmental education" began to affirm itself internationally and brought up for discussion the possibilities of understanding and combating climate change issues (Fernandes, Gomes, & Laporta, 2017).

According to Marinho et al. (2014) "environmental education" is shown as a guiding tool for the awareness of individuals on environmental issues, in which all the members of the society are seen as integral participants in the educational process. The authors also affirm that the "environmental education" has an interdisciplinary character, which has to be considered in the theories and practices that underlie educational actions on climate change.

Although there are several environmental education initiatives related to the climate change issue in Brazil, they do not establish a profound relationship between everyday actions and their

synergies (e.g. transportation, excessive consumption, land change processes) with the increase of greenhouse gases emission (Ghilardi-Lopes et al., 2013). In addition, many studies have shown that environmental education is not a priority in schools and in continuing education programs for teachers (Lappa, Kyparissos, & Paraskevopoulos, 2017). Finally, if we consider "marine environmental education" in Brazil the initiatives are rare (Berchez et al., 2007), despite their vast importance in the development of a conscience focused on the conservation of marine ecosystems.

## 4 Related Works

In the late of 1970s, the emergence of serious games changed the traditional concepts of education (Yusoff et al., 2018). Some recent studies show that serious games can increase knowledge acquisition, perceptual and cognitive skills, motor skills, behavior change, soft skills and social skills (Connolly et al., 2012; Marsh, 2016; Rossano, Roselli, & Calvano, 2017). In this context, they can be powerful tools to teach about sustainability issues at school, since these abilities are important if we consider the characteristics of modern society.

For example, the work of Jean et al. (2017) relies on interdisciplinarity by proposing the use of the Scratch tool in the construction of learning objects related to sustainability issues as an alternative for the enrichment of pedagogical practices in schools. All involved subjects - researchers and students - played an active role during the development of the project, which resulted in a critical-collaborative action research. After learning how to handle the tool, the 34 students defined topics such as 3R's Policy (recycling, reusing and reducing), Recyclable Materials, Sustainable Development and received instructions on how to base the materials developed. Such materials, as games and animations, were shared with the other students in the school. The pedagogical aspects of the learning objects were analyzed by the criteria: interactivity, autonomy, cooperation, cognition, and affectivity. The study concluded that there was greater effectiveness in the subject developers and less effectiveness in the user's subjects.

Learmonth Sr. & Bobko (2011) present in their work the result of the game "UVa Bay Game", a decision-making simulator that provides a learning environment raising awareness about sustainability issues, having the already published data about the health of the Chesapeake Bay as a comparative parameter for the development of the simulator. In a collaborative effort of diverse areas, such as natural sciences, politics and social sciences, undergraduate students will have undergone interdisciplinary learning before playing 10 annual rounds of the Bay Game by 2020. As a result of the simulations, thanks to the choices made for low impact practices or organic agriculture, the improvement in the general health of the Bay stands out. Also, there was a positive economic impact, a fact that brought up the discussion of government policies to encourage good

practices. Players were able to learn the relationship between human decisions and their consequences for the bay health.

If we consider games related to marine ecosystems, we can cite the game “Preserve the Coral” (Marques et al., 2013), which was developed with the goal of bringing players closer to the theme of environmental conservation of coral reefs. Through the use of Artificial Intelligence to represent knowledge from a basis of production rules, it demonstrates what would happen if certain actions caused coral degradation. The scenario of the game is composed of the seabed, coral reefs and biodiversity elements. The characters of the game are: artificial reef, seaweed, jellyfish, fish, sea urchin, scuba diver, dragging nets, oil, and garbage. The player loses points for each interaction with the coral which is incompatible with its protection.

Another example is the “Ocean Simulator” learning object (Silva & Alves, 2017), which seeks to recreate the oceanic environment through the insertion of ecological parameters, such as food chain and energy pyramid. The player can freely create a simulation environment by inserting and interacting with NPCs (Non Player Characters) that mimic the behaviors of marine animals. Thus, it is possible to learn important information about the marine ecosystem and its functioning, arousing the interest for the conservation of this environment.

Finally, the game “Tartarugas” (Santos Filho et al., 2008), which was elaborated by an interdisciplinary team, aims to complement students’ learning about turtles and their environment through interaction with conceptual maps, animated texts, and figures. The application of questionnaires was used as a methodology for evaluating the tool. The students answered the questions before and after the game, and thus it was possible to observe that it was a motivating resource for both the educator and the learners.

Like the “Apicum Game”, these Brazilian games have strong theoretical and pedagogical bases and seek to insert the student in a real situation context. In addition, the importance of interdisciplinarity in the elaboration of those learning objects focused on environmental education is highlighted. “Apicum Game” also aims to teach the steps of the scientific method (i.e. observation, hypothesis formulation, experimentation, description and discussion of results and conclusion) intuitively. Therefore, in contrast to other Brazilian environmental educational games, “Apicum Game” represents an opportunity to teach about the scientific method and its use for the investigation of environmental problems, according to the three structuring axes of scientific literacy (Ghilardi-Lopes et al., 2015), which are: (1) basic understanding of terms, scientific knowledge and concepts fundamental rights; (2) an understanding of the nature of science and the ethical and political factors follow their practice and (3) understanding of the relationships between science, technology society and environment (Sasseron & Carvalho, 2016).

## 5 Methodology

**“**Apicum Game” was presented to a private school located in the state of São Paulo. The school board agreed to test the prototype of the game with students between 7 and 12 years old during a 50 min period of a biology class. The students who took part of this study were in sixth grade of elementary school and had been introduced to topics related to climate change in previous classes.

The objectives of the game and of the research were presented to the students and those who wanted to take part on the study completed an informed consent form, which was also read and signed by their parents (or guardians). The consents indicated that the information provided by the students during the study would be used for research purposes and that the collection of data did not offer any risks for the participants. Also, they were informed that they would: 1) answer a pre-test questionnaire; 2) play the “Apicum Game” and 3) answer a post-test questionnaire. In this study, we considered only data provided by students who duly completed the informed consent form and answered at least one of the questionnaires.

Before the game test started, the participants were asked to complete the pre-test questionnaire composed by 19 questions: 5 questions about their personal information, 5 questions about their game habits and 9 about their previous knowledge about climate change and coastal environments. The main objective of the pre-test questionnaire was to identify the video-game habits of the participants and their previous knowledge on the topics explored in the game.

During the game test, the participants were referred to a computer room and spent 50 minutes playing the game. Also, participants who were not able to finish all the game stages in this period were asked to finish the game and complete the post-test questionnaire at home.

Finally, after finishing the game testing, the participants were asked to complete the posttest questionnaire composed by 18 questions: 5 questions about their personal information, 6 questions about the game impressions, 3 questions about the educational content presented in the game and 4 questions about their suggestions to the improvement of the game. The main objective of the post-test questionnaire was to stimulate the students to discuss the game aspects and give feedbacks about possible improvements. Also, the educational content questions of the post-test questionnaire alluded to the educational content questions of the pretest questionnaire, thus it was possible to correlate the answers given in both questionnaires to determine if the game succeeds in teaching the proposed topics.

The questionnaires were composed by closed and open questions. Also, in some of the closed questions, the students were able to choose more than one answer option. Thus, in order to analyze the data provided from closed questions, the answers were quantified and evaluated considering the frequency with which each possible question was marked by the respondent. In addition, open questions were analyzed using content analysis (Hsieh & Shannon, 2005), so that each response

was considered individually and, the units of meaning were extracted in order to define the main content of each answer and their frequency was calculated.

## 6 Results and Discussion

Thirty-three students, 20 boys and 13 girls from 6 different classes participated in the tests and answered the pre and the post-test questionnaires. Also, an additional number of thirty-four students (18 boys and 16 girls) answered just the pre-test questionnaire. The majority of students (94.0%) attended exclusively private schools (Figure 10).

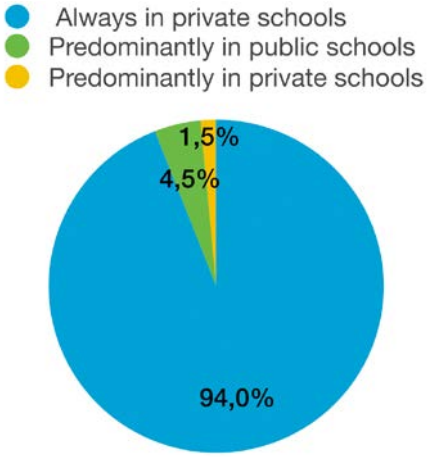



Figure 10: Number of students according to the type of school (private or public) they attended during their lives.

### 6.1 Pre-test questionnaire results

In this subsection we present the results obtained from the answers given by the sixty-seven students who completed the pre-test questionnaire.

The distribution of students' frequency of playing games (Figure 11) shows that most of the students (98.5%) have the habit of playing games occasionally or frequently and just 1 student affirmed not being in the habit of playing games. In the study of Wallenius et al. (2009), about 75–90% of school-aged children play digital games. Our study presented a higher percentage of students who play games than the frequency observed in the work of Wallenius et al.. This high percentage allows us to assume that the majority of the students of have some familiarity with games.

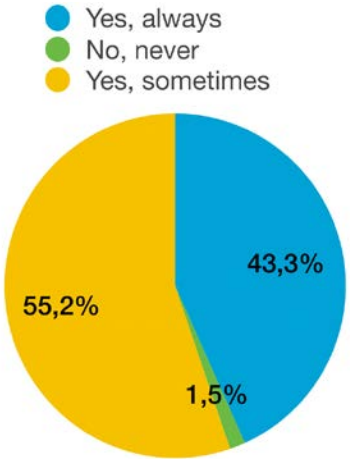



Figure 11: Percentage of answers regarding the frequency of playing games.

In our study, the majority of the students (59.7%) play games for entertainment purposes and just a few participants (3.0%) play games for educational purposes (Figure 12). According to the study of Iten & Petko (2016), classical game theories suggest that enjoyment is mainly related to freedom from utility, whereas learning games must be regarded as oriented activities rather than being just for fun and enjoyment. In addition, our results over the motivation for playing games is consistent to the work of Wallenius et al. (2009), which states that children rarely (2–4%) mention education or the opportunity to learn new skills as good things in computer games.

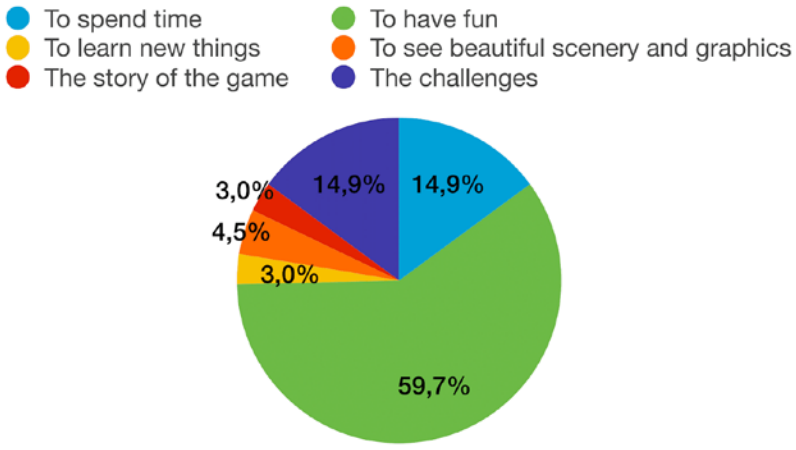



Figure 12: Percentage of answers regarding the motivation to play games.

Additionally, 4 students affirmed playing games on Facebook (Figure 13). The majority of the students (94.0%) do not have the habit of playing games on Facebook. Paavilainen, Alha & Korhonen (2017) affirm that Facebook has become the most popular social network service in the western world and most of the studies on social games focuses on games distributed in this platform. In this context, the study conducted by Wohn & Lee (2013) shows that players of social

network games have four expected outcomes: to build common ground, to reciprocate, to pass time, and to cope.

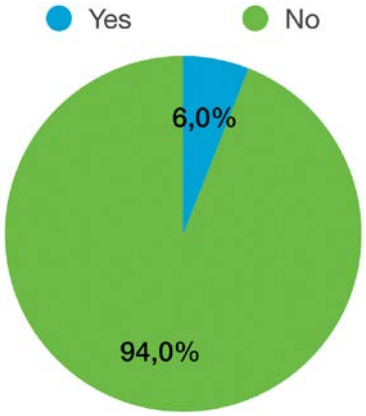



Figure 13: Percentage of answers regarding the frequency of playing games on Facebook.

Most of the students prefer to play games on video game consoles (49.3%) and games related to outdoor sports activities (53.7%) (Figure 14). In the console game market, one of the most striking trends is the surge of sales in "family entertainment" games (Voida & Greenberg, 2009). In addition, recent studies suggest a strong social motivations for group console games (Voida & Greenberg, 2009; Voida, Carpendale, & Greenberg, 2010; Voida & Greenberg, 2012). The study conducted by Voida & Greenberg (2012) emphasizes the importance of console games as a bridge among for multiple generations. The authors affirm that intergenerational interactions surrounding console gaming can provide some of the developmental benefits crucial to individual well-being.

Recent studies suggest that physical activity benefits children's academic performance and mental development (Resaland et al., 2015; Hills, Dengel, & Lubans, 2015). Based on the significant amount of time children spend at school, this sector has an important influence on promoting physical activities to children (Resaland et al., 2015; Hills, Dengel, & Lubans., 2015). Furthermore, schools have the potential to assist children in meeting their daily physical activity needs, since school setting offers opportunity for structured outdoor sports activities through physical education (Resaland et al., 2015; Hills, Dengel, & Lubans, 2015).

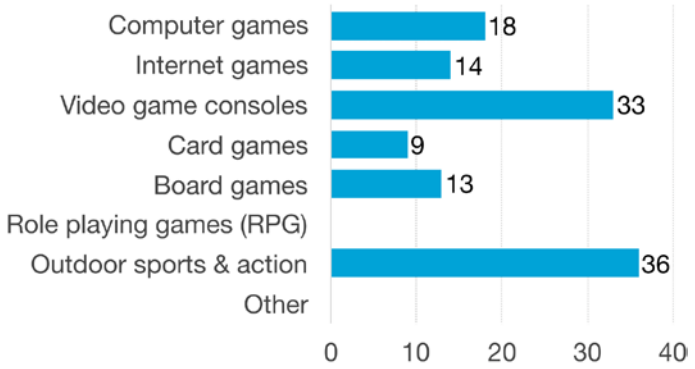



Figure 14: Number of answers regarding the type of games played by the students. More than one alternative was possible, since it was a multiple choice question.

In our study, most of the students (91.0%) have already heard about climate change before playing the game and 6 students affirmed that they never heard about climate changes (Figure 15). Climate change emerged as an environmental concern during the mid-1980s (Schultz & Bryant, 2016). In the 2000s, the risk perception of climate change increased as the topic has risen up the political agenda, and journalists have increasingly associated dramatic weather events with global climate change (Anderson, 2009). Also, recent studies suggest that levels of climate change awareness, knowledge, perceived risk, and support for mitigation or adaptation vary greatly across the world (Lee et al., 2015). In addition, understanding the anthropogenic cause of climate change is the strongest predictor of climate change risk perceptions and pro-environmental behavior (Lee et al., 2015; Capstick et al., 2015; Masud et al., 2015).

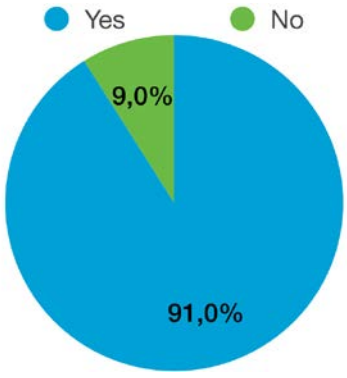



Figure 15: Percentage of answers regarding the awareness of climate change.

Also, most of the students have heard about climate change on TV (76.1%) or in school (74.6%) (Figure 16). In the work of Schmidt, Ivanova & Schäfer (2013), the authors conducted a comparative analysis of climate change attention in 27 countries. In this study, the authors included countries that have signed and ratified the Kyoto Protocol, and countries that are strongly affected by the consequences of climate change. The study describes the development of media attention for climate change in these countries from 1996 to 2010 and explores whether the media

attention reflects in climate change awareness and climate policies for a country. The authors state that newspapers around the world devote a considerable share of reporting space to climate change, playing a potentially significant role in influencing public perceptions.

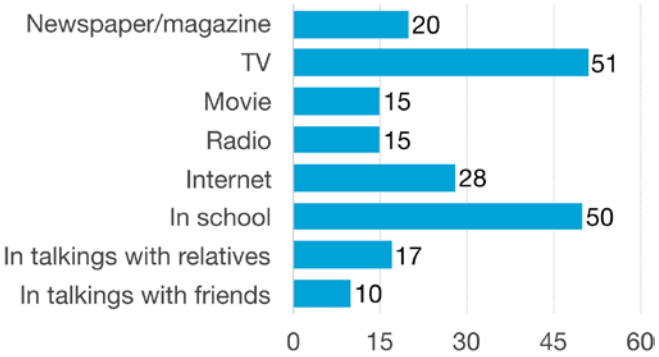



Figure 16: Percentage of answers regarding the type of media in which students heard of climate change. More than one alternative was possible, since it was a multiple choice question.

## 6.2 Comparable questionnaires' results

In this subsection we present the results related to the questions which were comparable between the pre and post-test questionnaires. Thirty-three students completed both questionnaires.

In the pre-test questionnaire, the participants were asked about what was their concept of "ecosystem". The majority of students (54.6%) considered that ecosystems are constituted of organisms, environmental factors and the interactions among them. Some students (33.3%) did not consider the interactions, citing in their answers only the biotic and abiotic factors. Two students (6.1%) considered only the biotic factors (organisms) as part of the ecosystems and one student (3.0%) considered only the abiotic factors (environment) as part of the ecosystem concept (Figure 17). After the game, they were asked to define "coastal ecosystem" and give an example. Most students (57.6%) gave an adequate definition of coastal ecosystem, mentioning the interaction of organisms and environment on coastal areas or near the ocean. However, 21.2% gave an inadequate definition and 18.2% answered they did not know (Figure 18). Of those 78.8% who answered the question, 57.7% were able to give an example of coastal ecosystem, as beaches, coral reefs or rocky shores.

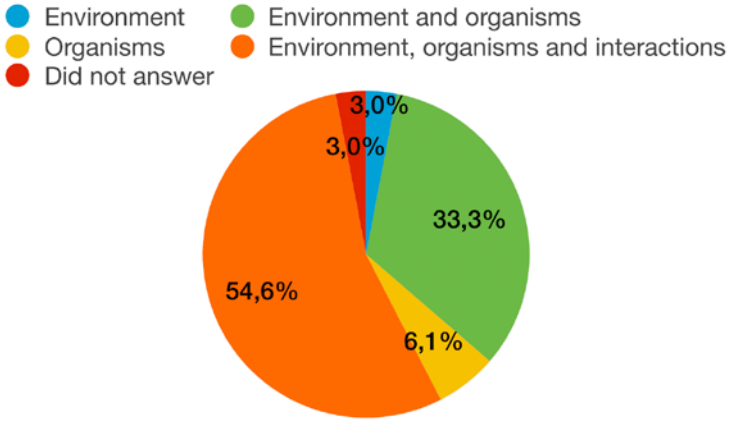



Figure 17: Percentage of answers regarding the concept of "ecosystem" by the students in the pre-test questionnaire.

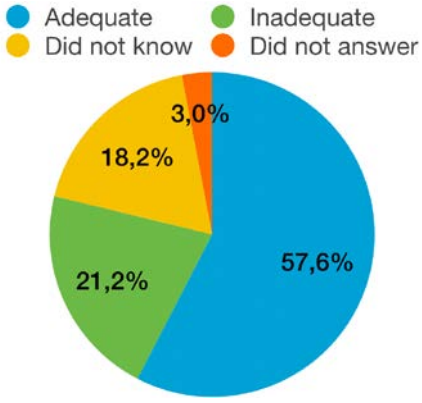



Figure 18: Percentage of answers regarding the concept of "coastal ecosystem" by the students in the post-test questionnaire.

In the pre-test questionnaire, the students were also asked about their concept of "climate change" (Figure 19). 60.6% of the students answered that climate change was related to alterations of the climate. Some of those related those alterations to a planetary, regional or local spatial scale. Although the definition given was not incorrect, the majority of the students (54.5%) incurred in a tautological argumentation, so it was not clear if the students really understood the meaning of the word "climate" or if they just used it because the term was already present in the question. Thus, as the arguments could be not analyzed (Simmons, 1960) in the answers given, we cannot consider them as evidences of knowledge. Only two students gave subsidies in their answers that indicated they really knew the concept: one of them explained the causes of climate change (increase in the concentration of greenhouse gases in the atmosphere) and related these causes with the alterations in the climate systems of the Earth; and the other mentioned that a climatic system can only be defined after long periods of study (30 years or more). On the other hand, the use of the word "weather" in the answers of 24.2% of the students was an indication that the students did not know the difference between "climate" and "weather", which is a common misconception of learners of this age (Choi et al., 2010). Also, the word "temperature" in some of

the answers (9.1%) indicated that students considered global warming as the definition of climate change, which is also common (Shepardson et al., 2009). According to Choi et al. (2010), misconceptions or a lack of relevant prior concepts can hinder students from developing an understanding of scientific concepts, which is fundamental for science literacy process (Sasseron & Carvalho, 2016).

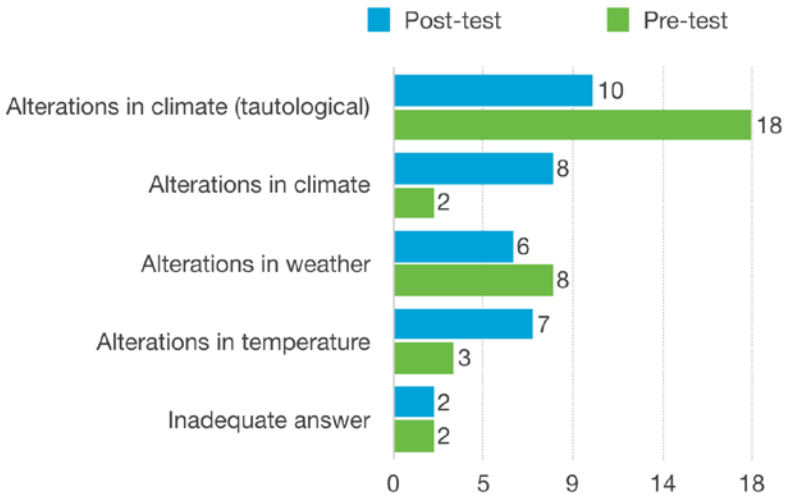



Figure 19: Number of citations in the answers of students of the concept of “climate change” by the students. More than one alternative was possible, since the question was open.

In the post-test questionnaire, the students were asked the same question about the concept of “climate change” (Figure 19). Again, many students mentioned the word climate in their answers and were tautological in their argumentation (30.3%). However, 24.2% of the students inserted elements in their answers related to the influence of humankind on climate change or gave examples of causes (global warming and alterations in the atmosphere) and consequences (increase in mean temperature, alterations in pluviosity or in the sea level) of climate change. There was an increase in the number of students who mentioned the word “temperature” in their answers, which could be possibly attributed to the introductory part of the game story in which the rise in mean temperatures in mentioned (although alterations in pluviosity is also mentioned in the same part of the game). In addition, it was possible to notice a subtle decrease in the number of answers which mentioned the word “weather”, which is positive. These results indicate a broadening in the conceptual profile of students in relation to the complex concept of climate change (Mortimer, 2016).

When asked if they could help mitigating climate change, most students answered “yes” (66.7%). In the pre-test questionnaire, 9 students did not answer and 1 did not know which kind of action they could take to mitigate climate change. In the post-test, only one student did not answer. Overall, in the post-test there was an increase in the number of possibilities cited by the

students, such as the decrease in pollution, decrease in global warming/greenhouse effect, decrease in deforestation, decrease in consumption, decrease in the use of fossil fuels and increase in the use of public transportation (Figure 20). According to Stevenson Nicholls & Whitehouse (2017), teachers must encourage students to think critically and creatively about approaches to climate change mitigation and adaptation and develop their capacity to respond with meaningful actions.

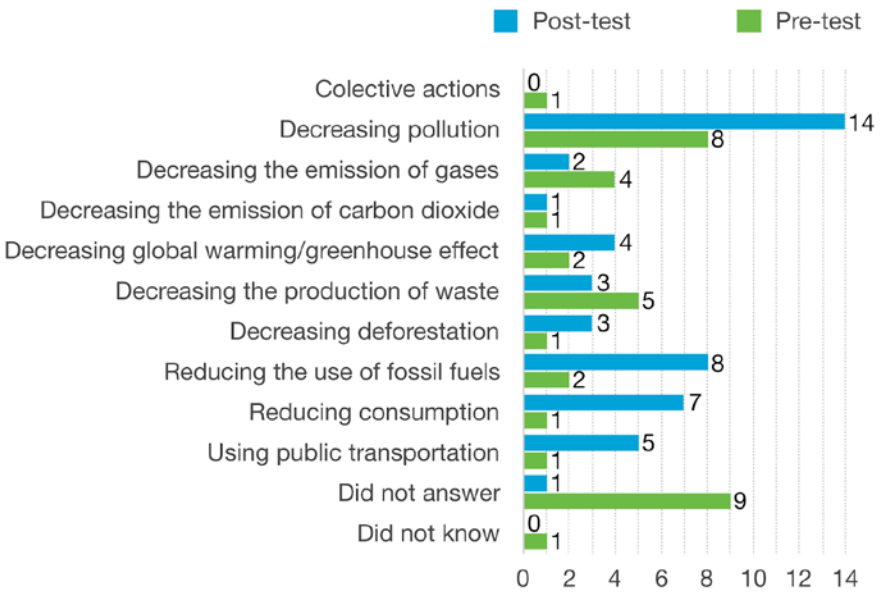



Figure 20: Number of citations in the answers of students of the actions that could help mitigate climate change. More than one alternative was possible, since the question was open.

### 6.3 Post-test questionnaire results

In this subsection we present the results obtained from the data collected from the post-test questionnaire, in which we considered the answers given by the thirty-three students who completed the pre and post-test questionnaires.

Most of the students chose the challenges (33.3%) and the educational content (30.3%) as the feature they most liked in the game (Figure 21). Amory et al. (1999) suggest that players prefer or are more motivated to play games with objectives requiring higher order thinking skills, including visualization strategies that nurture creative problem solving and decision-making.

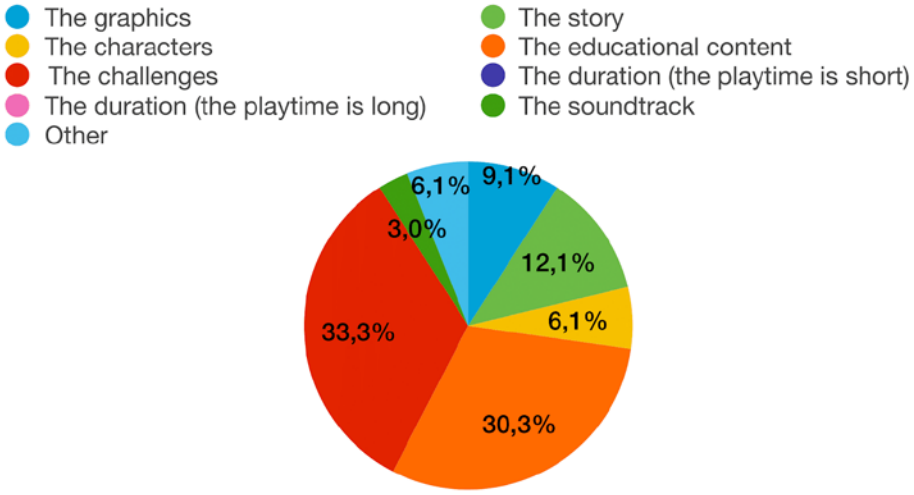



Figure 21: Percentage of answers regarding the features the students liked the most of the game.

In addition, the majority of students answered “other aspects” (27.3%) and the graphics (24.2%) as the feature they most disliked in the game (Figure 22). When asked which were the “other aspects” they disliked the most, 5 students declared that they found physics bugs during the playing time, which forced them to reset the game. According to Magerko, Heeter & Medler (2010), the participants of serious game tests have individual differences that may make a serious game particularly ineffective and uninteresting for some learners. Also, the authors affirm that the inherent disparity in the effectiveness of even well designed serious games is a problem that need be addressed by recognizing the individual differences between students and changing the game design and development practices to accommodate those differences.

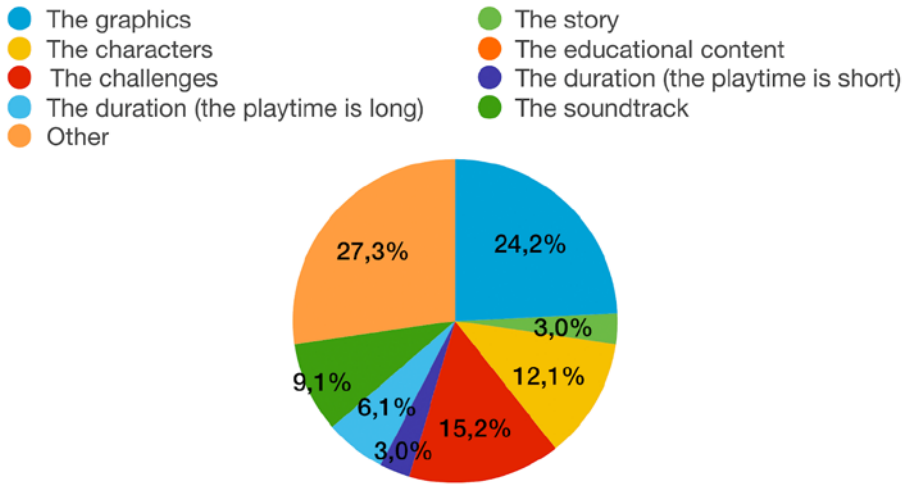



Figure 22: Percentage of answers regarding the features the students disliked the most of the game.

Two items assessed students’ future intentions regarding the “Apicum Game”. The first assessed intentions to play the game again, asking “Would you play the game again?”. The other

assessed their intention to recommend the game to someone else, asking “Would you recommend this game to a friend?”.

When asked if they intended to play the game again, most of the students declared that they were willing to play the game again (60.6%) and none of the students declared that they would not play the game again (Figure 23). In addition, 39.4% of the students answered “maybe” when asked about the possibility of playing the game again. According to Burgers et al. (2015), participants receiving negative feedback from a game are more inclined to play the game again immediately than participants receiving positive feedback. The authors suggest that the will to play the game again immediately is demonstrated by participants that want to redeem themselves, or to succeed better at the task proposed. Also, according to Skinner (1954), repeated playing serious games leads to more in-depth learning.

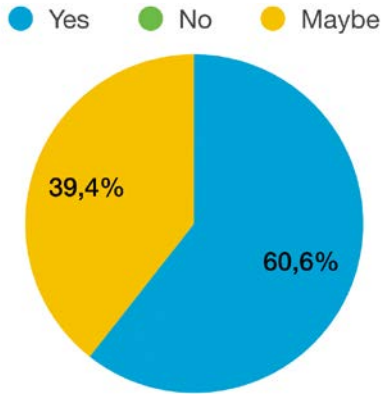



Figure 23: Percentage of answers regarding the chance of playing the game again.

When asked if they would recommend the game to a friend, the majority of students (69.7%) answered “yes”, some students answered “maybe” and none of the students answered “no” (Figure 24). Przybylski, Rigby & Ryan (2010) suggest a link between game recommendation intention with other factors, such as motivation for future play, enjoyment and game immersion.

Two items assessed students’ suggestions for improvements regarding the “Apicum Game”. The first assessed the recommendations for game improvement, asking “What suggestion would you give to improve the game?”. The other assessed the problems found during the game testing, asking “Please inform us if you have found any problem or bugs in the game”.

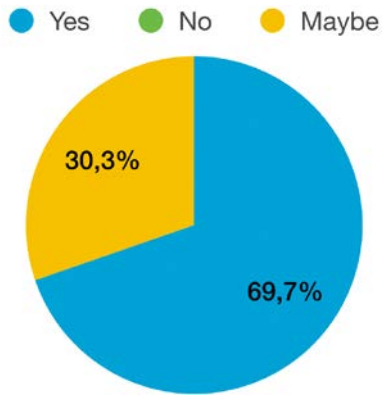



Figure 24: Percentage of answers regarding game recommendation to friends.

According to the distribution of suggestions for game improvements (Figure 25), most of the students recommended to fix some physics bugs found in the game (39.4%) and to improve the graphics (21.2%). According to Lewis, Whitehead & Wardrip-Fruin (2010) difficulty in designing and testing games invariably leads to failures being present in the game, negatively impacting the experience of the players.

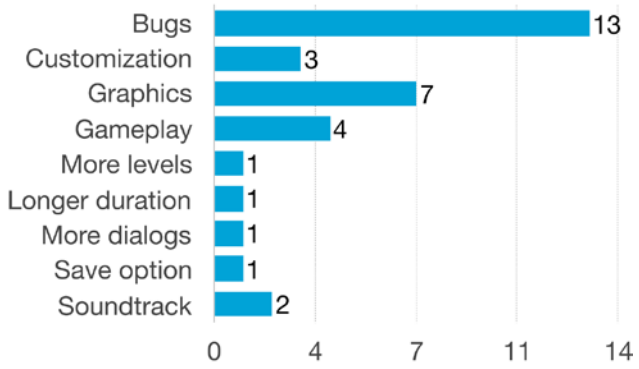



Figure 25: Number of students according to their suggestions for game improvements. More than one alternative was possible, since the question was open.

Also, when asked about problems found during the game-play (Figure 26), most of the students declared that they found some physics bugs in the game (63.7%). In addition, 1 student that the game duration was too short and 1 student mentioned that the graphics need to be improved.

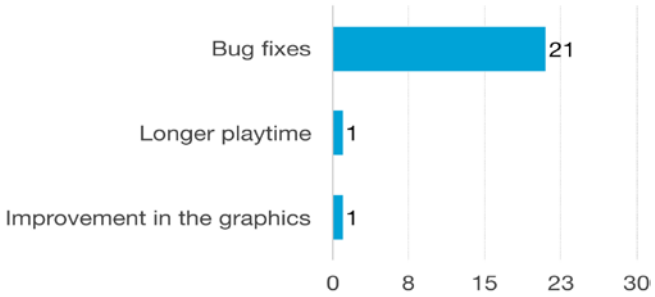



Figure 26: Number of students according to the problems found in the game. More than one alternative was possible, since the question was open.

Finally, two items assessed students' learning process regarding the "Apicum Game". The first assessed the occurrence of learning during the game testing, asking "Did you learn new things playing the game?". The other assessed the concepts learned during the game testing, asking "Give an example of something you learned from the game".

The majority of students affirm that they learned new things with the game (60.6%) and some students affirm that they did not learn anything new in the game (39.4%) (Figure 27). According to Alincak (2016), game is an effective tool for mental and cognitive development of students, since game activities promote knowledge acquisition through inquiry, trial, experience and creative thinking for learning.

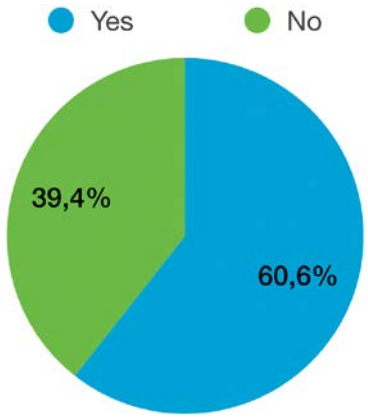



Figure 27: Percentage of answers regarding the knowledge acquisition regarding the contents of the game.

When asked to give an example of something they learned in the game, most of the students answered "awareness of climate change" (24.2%). Also, 5 students declared that they did not learn anything new by playing the game (Figure 28).

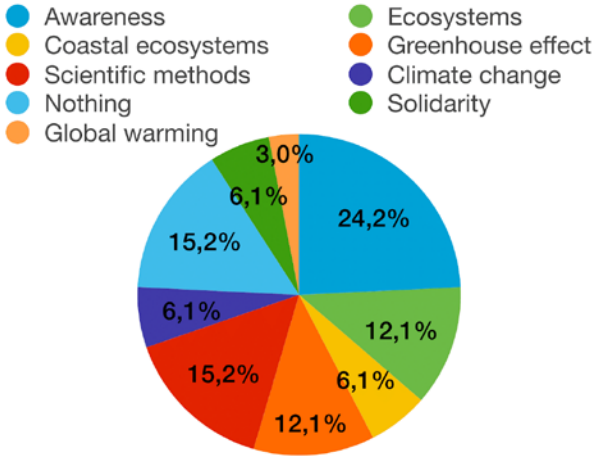



Figure 28: Percentage of answers regarding the contents of the game learned by the students.

## 7 Conclusions

This work showed that students who participated in the research generally play video games for fun. Also, they have already heard about climate change, mainly in television and school.

It was possible to notice that the majority of students understood the concept of coastal ecosystems, which was addressed in the game. Also, the game contributed to broadening the conceptual profile of students in relation to the complex concept of climate change, with a decrease in the use of tautological answers; a decrease in the misuse of the term “weather” to refer to the concept of “climate”; an increase in the number of citations of the human influence on climate change and in the number of citations of causes and consequences of climate change. Finally, the game contributed to an increase in the number of actions cited by the students to mitigate climate change, such as the decrease in pollution, decrease in global warming/greenhouse effect, decrease in deforestation, decrease in consumption, decrease in the use of fossil fuels and increase in the use of public transportation.

The auto-assessment of the students indicated they learned from the game and that the educational content and challenges presented along the story were appreciated by them. Most of the students would play again or indicate the game to a friend. However, the graphics and some bugs must be improved/fixed so as to make the game more enjoyable. For future works, we intend to fix the bugs reported during the test of the game prototype, and execute the test again considering game flow and player engagement.

## Acknowledgements

We thank FAPESP (process no 2012/03922-3) for the financial support.

## References

Alıncak, F. (2016). Evaluation of opinions of primary school teachers on the method of education with game. European Journal of Physical Education and Sport Science, 2(3), 81–96. [DOI: 10.5281/zenodo.159875] [GS Search]

Amory, A., Naicker, K., Vincent, J., & Adams, C. (1999). The use of computer games as educational tool: identification of appropriate game types and game elements. British Journal of Educational Technology, 30(4), 311–321. [DOI: 10.1111/1467-8535.00121] [GS Search]

Anderson, A. (2009). Media, politics and climate change: Towards a new research agenda. Sociology Compass, 3(2), 166–182. [DOI: 10.1111/j.1751-9020.2008.00188.x] [GS Search]

Beck, U. (1997). Modernização reflexiva: política, tradição e estética na ordem social moderna. Editora UNESP. [GS Search]

Beck, U. (2011). Sociedade de risco: rumo a uma outra modernidade. Editora 34. [GS Search]

Berchez, F., Ghilardi, N., Robim, M. J., Pedrini, A. G., Hadel, V. F., Fluckiger, G., et al. (2007). Projeto trilha subaquática: sugestão de diretrizes para a criação de modelos de educação ambiental em unidades de conservação ligadas a ecossistemas marinhos. OLAM Ciência & Tecnologia, 7(3), 181–209. [GS Search]

Brasil (2000). Parâmetros Curriculares Nacionais – Ensino Médio. Brasília: MEC.

Burgers, C., Eden, A., van Engelenburg, M. D., & Buningh, S. (2015). How feedback boosts motivation and play in a brain-training game. Computers in Human Behavior, 48(1), 94-103. [DOI: 10.1016/j.chb.2015.01.038] [GS Search]

Canotilho, J. J. G. (2010). O princípio da sustentabilidade como princípio estruturante do direito constitucional. Tékhne-Revista de Estudos Politécnicos, 13, 07–18. [GS Search]

Capstick, S., Whitmarsh, L., Poortinga,W., Pidgeon, N., & Upham, P. (2015). International trends in public perceptions of climate change over the past quarter century. Wiley Interdisciplinary Reviews: Climate Change, 6(1), 35–61. [DOI: 10.1002/wcc.321] [GS Search]

Choi, S., Niyogi, D., Shepardson, D. P., & Charusombat, U. (2010). Do earth and environmental science textbooks promote middle and high school students' conceptual development about climate change? textbooks' consideration of students' misconceptions. Bulletin of the American Meteorological Society, 91(7), 889–898. [DOI: 10.1175/2009BAMS2625.1] [GS Search]

Connolly, T. M., Boyle, E. A., MacArthur, E., Hainey, T., & Boyle, J. M. (2012). A systematic literature review of empirical evidence on computer games and serious games. Computers & Education, 59(2), 661–686. [DOI: 10.1016/j.compedu.2012.03.004] [GS Search]

Cruz, S. M. S. C. (2001). Aprendizagem centrada em eventos: uma experiência com o enfoque ciência, tecnologia e sociedade no ensino fundamental. Universidade Federal de Santa Catarina. [GS Search]

Delizoicov, D., Angotti, J. A., Pernambuco, M. M., & da Silva, A. F. G. (2002). Ensino de ciências: fundamentos e métodos. Cortez Editora. [GS Search]

Fernandes, I. G., Gomes, A. A., & Laporta, J. L. (2017). Educação ambiental marinha na reserva de desenvolvimento sustentável barra do Una, Peruíbe (SP). Revista Brasileira de Educação Ambiental, 12(1), 177–194. [GS Search]

Field, C. B., Barros, V., Stocker, T. F., & Dahe, Q. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation: special report of the intergovernmental panel on climate change. Cambridge University Press. [GS Search]

García, J. E. (1998). Hacia una teoría alternativa sobre los contenidos escolares. Díada. [GS Search]

Ghilardi-Lopes, N., Silva, L., Ribeiro, T., & Braga, J. C. B. (2015). Apicum game um software educativo sobre mudanças climáticas e seus efeitos nos ambientes marinhos e costeiros. Proceedings of VI Congresso Brasileiro de Informática na Educação, 302–309. [DOI: 10.5753/cbie.wcbie.2015.302] [GS Search]

Ghilardi-Lopes, N. P., Braga, J. C., Silva, L., Freitas, S. R., & Ribeiro, T. (2013). Environmental education through an online game about global environmental changes and their effects on coastal and marine ecosystems. Proceedings of XII Simpósio Brasileiro de Jogos e Entretenimento Digital, 469–474. [GS Search]

Hansmann, R., Mieg, H. A., & Frischknecht, P. (2012). Principal sustainability components:empirical analysis of synergies between the three pillars of sustainability. International Journal of Sustainable Development & World Ecology, 19(5), 451–459. [DOI: 10.1080/13504509.2012.696220] [GS Search]

Harley, C. D. G., Randall Hughes, A., Hultgren, K. M., Miner, B. G., Sorte, C. J. B., Thornber, C. S., et al. (2006). The impacts of climate change in coastal marine systems. Ecology Letters, 9(2), 228–241. [DOI: 10.1111/j.1461-0248.2005.00871.x] [GS Search]

Hills, A. P., Dengel, D. R., & Lubans, D. R. (2015). Supporting public health priorities: recommendations for physical education and physical activity promotion in schools. Progress in Cardiovascular Diseases, 57(4), 368–374. [DOI: 10.1016/j.pcad.2014.09.010] [GS Search]

Hoegh-Guldberg, O., & Bruno, J. F. (2010). The impact of climate change on the world's marine ecosystems. Science, 328(5985), 1523–1528. [DOI: 10.1126/science.1189930] [GS Search]

Hsieh, H. F., & Shannon, S. E. (2005). Three approaches to qualitative content analysis. Qualitative Health Research, 15(9), 1277–1288. [DOI: 10.1177/1049732305276687] [GS Search]

Iten, N., & Petko, D. (2016). Learning with serious games: Is fun playing the game a predictor of learning success? British Journal of Educational Technology, 47(1), 151–163. [DOI: 10.1111/bjet.12226] [GS Search]

Jacobi, P. R. (2005). Educação ambiental: o desafio da construção de um pensamento crítico, complexo e reflexivo. Educação e Pesquisa, 31(2), 233–250. [GS Search]

Jacobi, P. R., Monteiro, F., & Fernandes, M. L. B. (2009). Educação e sustentabilidade: caminhos e práticas para uma educação transformadora. São Paulo: Evoluir Cultural. [GS Search]

Jean, E. N. S., Oliveira, E. S., De Souza, A. H., De Oliveira Marques, E. S., Yoshio Kanda, J., et al. (2017). Educação ambiental: um trabalho interdisciplinar utilizando a ferramenta "scratch" com alunos do ensino médio na construção de objetos de aprendizagem. Proceedings of X Congreso Internacional sobre Investigación en Didáctica De las Ciencias, 3363–3368. [GS Search]

Jose, S., Patrick, P. G., & Moseley, C. (2017). Experiential learning theory: the importance of outdoor classrooms in environmental education. International Journal of Science Education, Part B, 7(3), 269–284. [DOI: 10.1080/21548455.2016.1272144] [GS Search]

Kahriman-Ozturk, D., Olgan, R., & Guler, T. (2012). Preschool children's ideas on sustainable development: How preschool children perceive three pillars of sustainability with the regard to 7r. Educational Sciences: Theory and Practice, 12(4), 2987–2995. [GS Search]

Lappa, C., Kyparissos, N., & Paraskevopoulos, S. (2017). Environmental education at the special school: Opinions of special education teachers. Natural Sciences Education, 46(1), 1–10. [DOI: 10.4195/nse2017.02.0004] [GS Search]

Learmonth Sr, G. P., & Bobko, R. (2011). Informing water policy with large-scale, high fidelity simulation. Proceedings of the Association for Public Policy Analysis and Management Annual Meeting, University of Virginia, Charlottesville, VA, USA, 1 December 2011. [GS Search]

Lee, T. M., Markowitz, E. M., Howe, P. D., Ko, C.-Y., & Leiserowitz, A. A. (2015). Predictors of public climate change awareness and risk perception around the world. Nature Climate Change, 5(11), 1014–1020. [DOI: 10.1038/nclimate2728] [GS Search]

Lewis, C., Whitehead, J., & Wardrip-Fruin, N. (2010). What went wrong: a taxonomy of video game bugs. Proceedings of the 5th International Conference on the Foundations of Digital Games, 108–115. [DOI: 10.1145/1822348.1822363] [GS Search]

Magerko, B., Heeter, C., & Medler, B. (2010). Different strokes for different folks: Tapping into the hidden potential of serious games. Gaming and Cognition: Theories and Perspectives from the Learning Sciences, 255–280. [DOI: 10.4018/978-1-61520-717-6.ch012] [GS Search]

Marinho, A. A., Marques, M. L. A. P., da Silva, A. F., Araújo, J. E. Q., da Silva Queiroz, T. H., & de Almeida, I. D. A. (2014). A educação ambiental na formação da consciência ecológica. Caderno de Graduação-Ciências Exatas e Tecnológicas-UNIT-ALAGOAS, 1(1), 11–18. [GS Search]

Marques, P. C. F., de Godoy Barbosa, A. D., de Souza, J. N., Felix, Z. C., D'Emery, R. A., Silva-Cavalcanti, J. S., & de Serra Talhada, U. A. (2013). Simulação comportamental dos corais em seu ambiente natural: proposta de um jogo educacional. Revista Comunicação e Educação Ambiental, 3(2), 39–54. [GS Search]

Marsh, T. (2016). Slow serious games, interactions and play: Designing for positive and serious experience and reflection. Entertainment Computing, 14, 45–53. [DOI: 10.1016/j.entcom.2015.10.001] [GS Search]

Masud, M. M., Akhtar, R., Afroz, R., Al-Amin, A. Q., & Kari, F. B. (2015). Pro-environmental behavior and public understanding of climate change. Mitigation and Adaptation Strategies for Global Change, 20(4), 591–600. [DOI: 10.1007/s11027-013-9509-4] [GS Search]

Morin, E., & Lisboa, E. (2007). Introdução ao pensamento complexo. Sulina Porto Alegre. [GS Search]

Mortimer, E. F. (2016). Construtivismo, mudança conceitual e ensino de ciências: para onde vamos? Investigações em ensino de ciências, 1(1), 20–39. [GS Search]

Oliveira, W., Neto, S., da Silva Junior, C. G., & Bittencourt, I. I. (2015). Avaliação de jogos educativos: Uma abordagem no ensino de matemática. In Brazilian Symposium on Computers in Education, 26(1), 657–666. [DOI: 10.5753/cbie.sbie.2015.657] [GS Search]

Østergaard, E., Lieblein, G., Breland, T. A., & Francis, C. (2010). Students learning agroecology: Phenomenon-based education for responsible action. Journal of Agricultural Education and Extension, 16(1), 23–37. [DOI: 10.1080/13892240903533053] [GS Search]

Paavilainen, J., Alha, K., & Korhonen, H. (2017). A review of social features in social network games. Transactions of the Digital Games Research Association, 3(2), 113–142. [DOI: 10.26503/todigra.v3i2.71] [GS Search]

Przybylski, A. K., Rigby, C. S., & Ryan, R. M. (2010). A motivational model of video game engagement. Review of General Psychology, 14(2), 154–166. [DOI: 10.1037/a0019440] [GS Search]

Raworth, K. (2012). A safe and just space for humanity: can we live within the doughnut. Oxfam Policy and Practice: Climate Change and Resilience, 8(1), 1–26. [GS Search]

Resaland, G. K., Moe, V. F., Aadland, E., Steene-Johannessen, J., Glosvik, Ø., Andersen, J. R., et al. (2015). Active smarter kids (ask): Rationale and design of a cluster randomized controlled trial investigating the effects of daily physical activity on children's academic performance and risk factors for non-communicable diseases. BMC public health, 15(1), 709–718. [DOI: 10.1186/s12889-015-2049-y] [GS Search]

Riordan, M., & Klein, E. J. (2010). Environmental education in action: How expeditionary learning schools support classroom teachers in tackling issues of sustainability. Teacher Education Quarterly, 37(4), 119–137. [GS Search]

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E., et al. (2009a). Planetary boundaries: exploring the safe operating space for humanity. Ecology and Society, 14(2), 32. [GS Search]

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin III, F. S., Lambin, E. F., et al. (2009b). A safe operating space for humanity. Nature, 461(7263), 472–475. [DOI: 10.1038/461472a] [GS Search]

Rossano, V., Roselli, T., & Calvano, G. (2017). Multimedia technologies to foster ecological skills. Proceedings of IEEE Advanced Learning Technologies ICALT, 128–130. [DOI: 10.1109/ICALT.2017.76] [GS Search]

Santos Filho, J.W., Brito, C. E. N., Santos, C., Alves, A., & Schneider, H. (2008). Jogo tartarugas: Objeto de aprendizagem na educação ambiental. Proceedings of IV Seminário Jogos Eletrônicos, Educação e Comunicação, 1–9. [GS Search]

Sasseron, L. H., & Carvalho, A. M. P. (2016). Almejando a alfabetização científica no ensino fundamental: a proposição e a procura de indicadores do processo. Investigações em Ensino de Ciências, 13(3), 333–352. [GS Search]

Schmidt, A., Ivanova, A., & Schäfer, M. S. (2013). Media attention for climate change around the world: A comparative analysis of newspaper coverage in 27 countries. Global Environmental Change, 23(5), 1233–1248. [DOI: 10.1016/j.gloenvcha.2013.07.020] [GS Search]

Schultz, C. P., & Bryant, R. D. (2016). Game testing: All in one. Stylus Publishing, LLC. [GS Search]

Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2009). Seventh grade students' conceptions of global warming and climate change. Environmental Education Research, 15(5), 549–570. [DOI: 10.1080/13504620903114592] [GS Search]

Silva, L. D. L., & Alves, A. G. (2017). Ocean simulator: objeto de aprendizagem sobre a vida marinha. Proceedings of XVI Simpósio Brasileiro de Jogos e Entretenimento Digital, 549–570. [GS Search]

Simmons, J. R. (1960). The nature of argumentation. Speech Monographs, 27(5), 348-350. [DOI: 10.1080/03637756009375300] [GS Search]

Skinner, B. F. (1954). The science of learning and the art of teaching. Harvard Educational Review, 24, 86-97. [GS Search]

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., et al. (2015). Planetary boundaries: guiding human development on a changing planet. Science, 347(6223), 1259855. [DOI: 10.1126/science.1259855][GS Search]

Stern, N. (2008). The economics of climate change. American Economic Review: Papers & Proceedings, 98(2), 1-37. [GS Search]

Stevenson, R. B., Nicholls, J., & Whitehouse, H. (2017). What is climate change education? Curriculum Perspectives, 37(1), 67–71. [DOI: 10.1007/s41297-017-0015-9] [GS Search]

Urry, J. (2015). Climate change and society. Why the Social Sciences Matter. Springer, 45–59. [DOI: 10.1057/9781137269928_4] [GS Search]

Voida, A., & Greenberg, S. (2009). Wii all play: the console game as a computational meeting place. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 1559–1568. [DOI: 10.1145/1518701.1518940] [GS Search]

Voida, A., Carpendale, S., & Greenberg, S. (2010). The individual and the group in console gaming. Proceedings of the 2010 ACM Conference on Computer Supported Cooperative Work, 371–380. [DOI: 10.1145/1718918.1718983] [GS Search]

Voida, A., & Greenberg, S. (2012). Console gaming across generations: Exploring intergenerational interactions in collocated console gaming. Universal Access in the Information Society, 11(1), 45–56. [DOI: 10.1007/s10209-011-0232-1] [GS Search]

Wallenius, M., Rimpelä, A., Punamäki, R. L., & Lintonen, T. (2009). Digital game playing motives among adolescents: Relations to parent–child communication, school performance, sleeping habits, and perceived health. Journal of Applied Developmental Psychology, 30(4), 463–474. [DOI: 10.1016/j.appdev.2008.12.021] [GS Search]

Watanabe-Caramello, G., & Strieder, R. B. (2011). Elementos para desenvolver abordagens temáticas na perspectiva socioambiental complexa e reflexiva. Revista Electrónica de Enseñanza de las Ciencias, 10(3), 587–608. [GS Search]

Wohn, D. Y., & Lee, Y. H. (2013). Players of facebook games and how they play. Entertainment Computing, 4(3), 171–178. [DOI: 10.1016/j.entcom.2013.05.002] [GS Search]

Yusoff, Z., Kamsin, A., Shamshirband, S., & Chronopoulos, A. T. (2018). A survey of educational games as interaction design tools for affective learning: Thematic analysis taxonomy. Education and Information Technologies, 23(1), 393–418.[DOI: 10.1007/s10639-017-9610-5] [GS Search]