Learning Scenarios for Serious Educational Games with Creative Visualization in Natural Eco-Context

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Abstract: Serious educational games are increasingly helping to promote creativity, engagement and effective learning in modern education. The focus of this paper is on learning scenarios and their key role in the development of serious educational games with creative visualization to build competence in natural ecosystems, responsible management of natural resources and environmental protection, in the context of the ProNature project. In the development, a structured framework for developing game scenarios was set and followed, applying and integrating pedagogical principles, game design elements, and adaptive learning technologies to improve educational outcomes. The paper discusses the key dimensions of effective educational game design and provides insights into formalizing game scenarios and integrating them into a scalable, user-friendly platform. The findings highlight the potential of serious games to address critical environmental challenges while promoting innovative and inclusive learning experiences.

1 INTRODUCTION

The unprecedented proliferation of online gaming, becoming a key component of culture and society (Bertacchini & Borrione, 2012; Cerezo-Pizarro et al., 2023). Gamification (Hamari, 2019) is now an ever-present part of the modern era (Zhang et al., 2021; Mabalay, 2025). This has a huge impact on social trends and *necessitates the need to offer digital gaming solutions with high added cognitive value* (Koivisto & Hamari, 2019; Mohd et al., 2023). Considering that popular computer games can raise awareness, attract the interest of young people and increase the popularity of embedded content in virtual reality, more efforts should be made to use games in a broader perspective and benefit and especially to build and develop serious educational games (Ofosu-Ampong, 2020; Kobari et al., 2022; P K et al., 2023).

Despite the interest in this direction, there is a lack of evidence and evaluation on the potential of games to achieve creativity, effective learning and acquisition of useful knowledge and skills (Hamari et al., 2014; Qian & Clark, 2016; All et al., 2016; Chugh & Turnbull, 2023). Due to their advanced interactivity and multimedia interfaces, modern serious educational games can convey complex concepts and facts in a widely accessible and engaging way (Knox, 2023; Dahalan et al., 2024; Karimov et al., 2024; Sun et al., 2024). Serious educational games of the interactive system or simulator type rely on the additional pedagogical value of fun and competition. On the other hand, the rapid development of serious educational games

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towards building through virtual and mixed reality provides additional opportunities creative visualization and interactivity, collaboration and teamwork, leadership, communication, critical thinking, problem solving, flexibility and adaptability, global and social awareness, information and technology literacy, initiative, social responsibility and ethics (Zakrzewski et al., 2025; Nguyen-Viet & Nguyen-Viet, 2025).

Contemporary serious educational games are extremely valuable especially if their construction and consideration is the result of a collaborative effort between a team of specialists in digital technology, the target subject area to be studied and the pedagogy. A well-structured scenario must integrate both pedagogical principles and game design elements to ensure a balance between entertainment and learning. At the same time, to develop and implement effective learning tools, it is essential to consider all stakeholders (users, educators, families, researchers, developers/industries) (De Gloria et al., 2014).

All this would be difficult to achieve when there is no clear learning scenario, concept, learning content and use cases to develop the game in a specific learning context, with a learning objective and learning-focussed gameplay. The scenario in educational games plays a crucial role in creating an engaging and effective learning experience by directing the player's attention toward key educational objectives (Bellotti et al., 2010). In developing a serious educational game, one should follow and clearly articulate the learning characteristics, specify the role of each game object, the space (scene) in which the serious game takes place, the actions, and the expected outcome. It is also important for the scenario to be adaptive, allowing players to explore different strategies and observe the consequences of their decisions, which fosters a deeper understanding of the learning content. Recent studies emphasize the importance of incorporating adaptive learning technologies and personalized feedback mechanisms into serious games to enhance their educational impact (Lameras et al., 2021). Adaptive scenarios that respond to the player's progress and learning style significantly improve engagement and knowledge retention.

This paper focuses on the learning scenario (also called game scenario) of a serious educational game, its formalization and development in a special learning-supported software platform. The target scenario reflects the specific learning content and player (learner) activities and in particular the specifics of the learning game objects, game scene, learning strategy, gaming learning flow, *etc*. The development of learning scenarios is a key component in the ProNature project (https://pronature-project.math.bas.bg), which aims *to develop an innovative software platform for serious educational games with creative visualization* to build competence for natural ecosystems, responsible management of natural resources and environmental protection. The project creates scenarios for serious educational games in the context of:

- awareness and knowledge about the functioning of protected ecosystems;
- sustainable use, protection and management of natural resources;
- pollution prevention and control;
- protection and responses in critical situations of biodiversity and natural ecosystems, *etc*.

In Section 2, the specifics of serious game design, focusing on the integration of pedagogical principles and game mechanics to create engaging and effective learning experiences, is explored. Section 3 presents the formalization and specification of a learning scenario of a serious educational game with creative visualization for building competence in natural ecosystems, responsible management of natural resources and environmental protection, providing a structured approach to defining game objects, activities and outcomes within a specific learning context. The design of the ProNature platform, highlighting its modular architecture and the role of the game scenario module in facilitating the creation of adaptable and reusable educational games, is presented in Section 4. Section 5 discusses some key dimensions of successful serious games, including learning-related, game-related and technical aspects. In Part 6, conclusions are drawn and views on future research and development are presented.

2 SERIOUS GAME DESIGN SPECIFICS

The acceptance and popularity of gamification as a strategy designed to boost user engagement, enhance motivation, and deliver lasting experiences attracted much attention (Bozkurt and Durak, 2018). A lot of research shows that this innovative approach has gained significant recognition and nowadays serious games and game-based learning mechanisms have been used to promote positive attitudes, behaviours, and learning achievements across various domains, including primary, secondary and higher education, adult education, healthcare, professional learning and

training, culture and social field (Lee et al., 2024; Bijl et al., 2024; Dernat et al., 2025). The thorough analysis of the theories used in primary studies related to gamification and serious games (Bozkurt and Durak, 2018; Krath et al.,2021) shows that a variety of theories are employed (more than 100). However, Self-Determination Theory (Mora et al., 2017; Thomas et al., 2020; Tobon et al., 2020) and Flow Theory (Bozkurt and Durak, 2018; Ab Jalil et al., 2020; Gris and Bengtson, 2021) emerged as the most beneficial frameworks in gamification research. Creating an educational game is a challenging task. The process involves integrating diverse perspectives, including essential learning theories and principles combined with effective game design and suitable educational content to ensure an engaging experience and educational effectiveness (Mifrah, 2023).

Researchers in the field have identified 12 key elements of effective educational game design and classified them into the framework including the following 4 dimensions (Prensky, 2003; Shute and Ke, 2012; Whitton, 2012):

- Learner-specific - profile, role, competencies;
- Pedagogy - associative, cognitive, social/situative;
- Representation\Action-Domain Link - fidelity, interactivity, immersion;
- Context - environment, access to learning, supporting resources.

The developed framework was extended further by incorporating cognitive and instructional approaches to be used in educational game development, known as the Four Dimensional Framework (FDF). The Table 1 below shows the core elements of FDF (De Freitas and Jarvis, 2009).

Table 1: FDF core elements.

Learner-specific	Pedagogy
Challenge Conflict Progress	Adaptation Assessment/Feedback Debriefing/Evaluation Instructions/Help/Hints Safety
Representation	**Context**
Control Interaction (Equipment), Interaction (Interpersonal), Interaction (Social) Location Problem-Learner Link Representation Sensory Stimuli	Fantasy Goal/Objectives Language/Communication Mystery Pieces or Players Player Composition Rules Theme

The FDF has been enhanced by incorporating cognitive and instructional approaches into the game process (van Staalduinen et al., 2010, Ahmad et al., 2015). Figure 1 illustrates how to connect the educational game elements across the four mentioned dimensions. Learning objectives and player goals shape the engagement of the learners (*i.e.* players) and guide the learning process. Based on their achievements in the game, the learners receive feedback and assistance from the system aiming to improve their learning effectiveness and behaviour. The changes in behaviour and achievements affect the learning content, leading to adjustments in the complexity level of the same topic or a transition to a different topic. This, in return, influences the learning objectives and player goals.

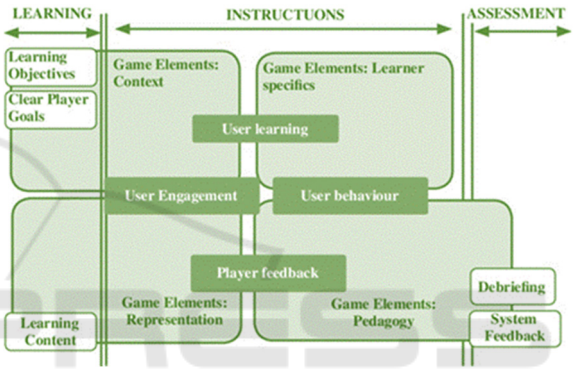

Figure 1: Improved FDF (Ahmad et al., 2015).

Emerging technologies such as generative AI, extended reality (XR), and real-time analytics provide opportunities to create more adaptive and realistic learning scenarios. Current solutions often fail to leverage these advances outlining a field for further improvement (Kamalov et al., 2023; Li, S & Zhou, Y., 2022; Ratican, J., Hutson, J., Wright, A., 2023). Another consideration is the existing need for personalized, inclusive, and scalable serious game solutions that cater to varying skill levels and goals. The focus of educational development should prioritize sustainability and equity. This is particularly relevant in the context of game-based learning platforms, where there is an increasing emphasis on the need for accessible and cost-effective tools. Many existing platforms, however, are characterized by being resource-intensive or prohibitively expensive, thereby significantly restricting their potential for widespread adoption. Addressing these barriers is imperative to ensure inclusive access to educational resources and to foster broader participation across diverse socio-economic groups.

The development of an innovative software platform for serious educational games with creative visualization to build competence for natural ecosystems, responsible management of natural resources and environmental protection (also called ProNature platform) is one of the main objectives of the ProNature project (https://pronature-project.math.bas.bg). Wide range of serious educational games with creative visualization in selected eco-contexts on the basis of created game educational scenarios, will be developed through the platform. The resulting games are mainly oriented towards students at the junior and senior secondary level but would also be of interest to representatives of the scientific community, educational institutions, NGOs, industry and society in general.

The proposed software platform and the serious educational games are aimed at contributing to the awareness of natural resources and ecosystems, to the creation of practical skills in students to design environmentally sustainable solutions. In general, the ProNature software platform is aimed at stimulating innovative thinking in solving environmental problems of the future towards sustainable management practices in industry and social life (Goynov et al., 2024). The methodology for the development of the serious game scenarios and their design specifics in the ProNature project considers the extreme dynamics of the development of the subject area, the applied research in it and the interdisciplinarity, which helps the developed models, methods and tools to be flexible, extensible and reusable.

3 FORMALIZATION AND SPECIFICATION OF SCENARIOS OF A SERIOUS EDUCATIONAL GAME WITH CREATIVE VISUALIZATION TO BUILD COMPETENCE FOR NATURAL ECOSYSTEMS, RESPONSIBLE MANAGEMENT OF NATURAL RESOURCES AND ENVIRONMENTAL PROTECTION

The game scenario is presented as a distinct component within a broader software architecture designed for the ProNature platform.

The architecture (Fig. 2) tries to isolate the components in order to divide and simplify the process of a serious educational game creation by strictly separating the tasks of:

- Creating and selecting the game artefacts - texts, audio and visual assets (2D or 3D), animations, configurable embeddable mini-games;
- Creating the scenario by defining a flow of sequences;
- Defining game rules;
- Creating the complete game using the desired environment (2D or 3D), scenarios, artefacts and rules using interactive software tools.

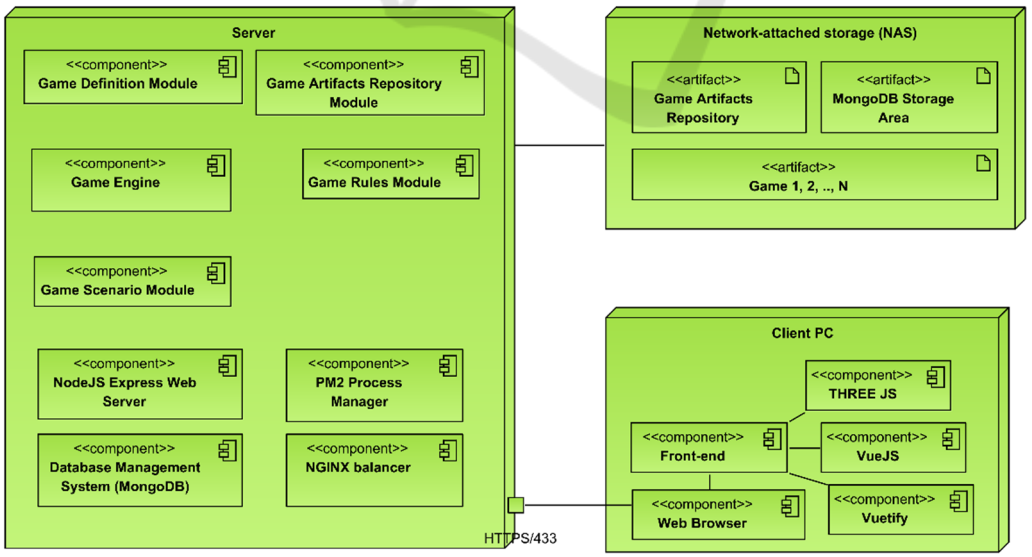

Figure 2: General software architecture of the ProNature platform.

The isolation of the components also gives a certain level of abstraction which would allow game developers to experiment by combining one game scenario with various sets of game artefacts or rules, or to use one scenario for different games.

Component inheritance will also be supported, meaning that a game (or game component) created by one game developer could be inherited, cloned and modified by another developer.

3.1 Formal Presentation of a Learning Scenario

A well-structured and not complicated formal definition of a game scenario is needed in order to put a stable foundation for the whole game process implementation. Game scenario development as a predecessor step of the actual game development should be done in a very precise and thoughtful way in order to reduce double work and rework on the next stages of the game development process.

For this reason our team set up a scenario definition (shown on the analytical design diagram below), containing a very simple repetitive flow, composed of very few entities:

- A scene, which defines the current environment and its descriptions, an introduction containing short educational parts, a game scenario may contain more than one scenes;
- Game objects, artifacts which are parts of the scene. They contain valuable educational content and allow interaction with players. Game object may have 3 statuses:
  - active - the player is able to interact and play (go through the scenario);
  - locked - the player will be able to interact after some other actions are completed, or a certain number of game points are gathered;
  - completed - the player has completed all scenario activities related to this game object. Player is still able to replay them.
- Available activities. Every game object contains a list of available activities related to its specific features. Activities can be specific tasks or cases to be solved by the players
- Outcomes. Activities are related to their relevant outcomes. Outcomes depend on player ' s decisions when playing with the specific part of the scenario (solving a game object' s specific task).

Figure 3 presents a diagram of the analysis for game scenario formalization. The purpose of the diagram is to show the object classes and the relationships between them concerning the basic elements of a game scene. Each scene consists of game objects that can be active, locked or completed. Active objects are those that are available for player interaction. Locked objects are those objects that are not yet available for player interaction, but a certain condition needs to be met for them to go into active status. Completed are all objects that the player has already played.

Each game object contains possible actions for the player to choose. Each action, in turn, provides a choice of possible outcomes.

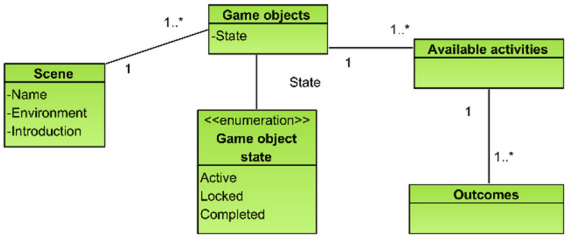

Figure 3: Diagram of the analysis for game scenario formalization.

3.2 Presentation of Content of Specific Learning Scenarios

The descriptors of a particular scenario directly depend on the learning content that is the subject of the game and are specified and grouped as general and specific. General descriptors mainly refer to genre, player characteristics, scenario context, general description and learning objective, learning characteristics, scene (space, terrain) on which the game will take place, inventory, active objects and their representation, game flow/development. Figure 4 represents an activity diagram of the game progress. It tracks the steps the learner (player) goes through to advance a level in the game. The activity diagram presents the flow of interactions between the system and the player while performing the game scenario.

A scene begins with a short introduction which aims to let the player into the scene details and to provide some contextual information about the target scene environment. As a rule of the thumb we assume that the introduction should not be longer than 30 seconds in order to keep the player's attention.

Next, the scene environment with game objects is presented to the player. Player is able to observe the whole environment and decide to continue with some of the active game objects.

Choosing a game object leads to presenting additional information or a list of specific tasks related to the object. The player is able to select a task

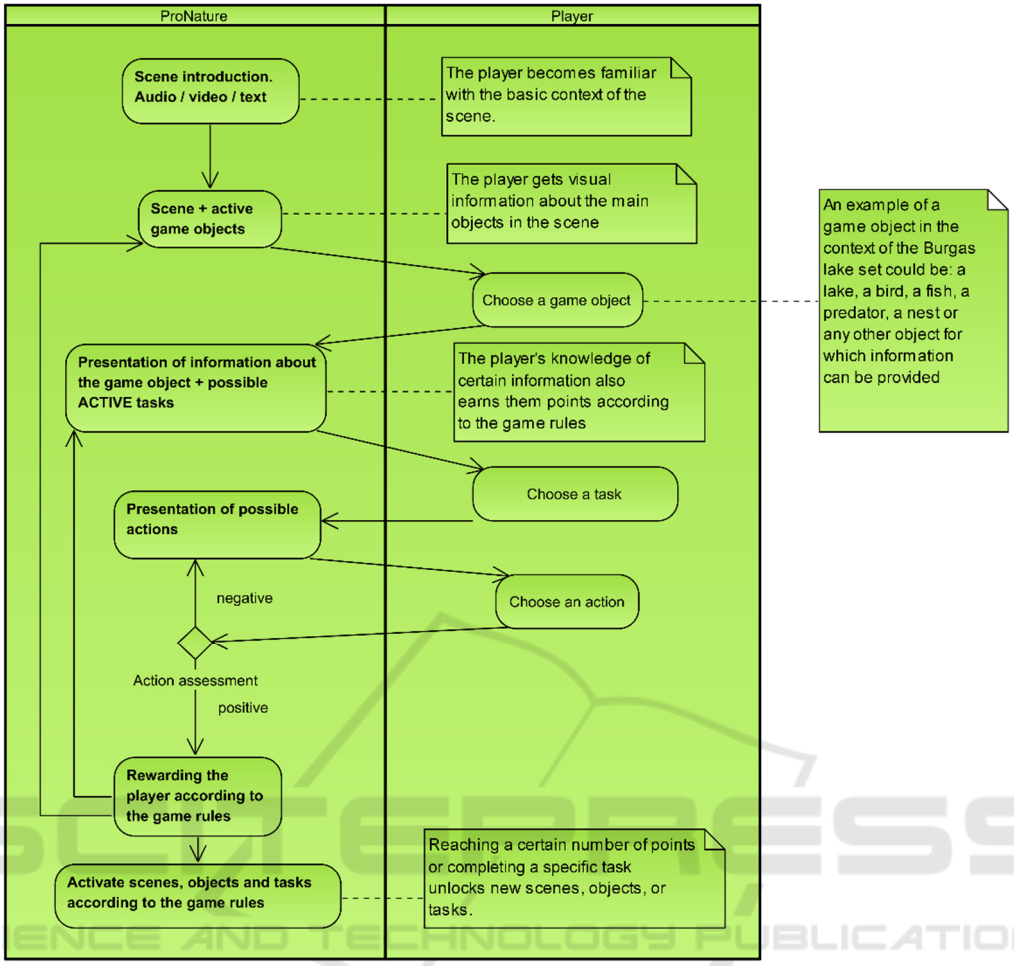

Figure 4: Activity diagram of the game progress.

to complete and possible ways of its completion. The system estimates the completion of the task and according to the game rules decides whether it was successful. According to the game rules, players could be awarded, new scenes / levels / game objects can be unlocked.

The specific descriptors are related to the specification of the selected active objects. For example, in Scenario 1, the first level is cognitive in the context of *awareness and knowledge about the functioning of protected ecosystems*. The actions of the learner (player) are related to exploring and learning educational information and interesting facts about the lake and its inhabitants. The player learns about some of the most important birds by researching basic characteristics and features about each bird. We selected the Atanasovsko lake and its inhabitants - the birds Dalmatian Pelican, Pied Avocet, Shelduck, White-tailed Eagle и Common Tern. For example, for the selected active object "bird" descriptors are included such as: distinctive features, specific information, how, where and what it eats (in general), habitat, nesting, residence in Bulgaria, who its enemies are (in general), why it is a protected species, interesting facts. Visualization through 2D and/or 3D images and sound and interactive learning units that teach and test the acquired knowledge are included (Figure 5). In the second level, the focus is on the food of birds and the specific descriptors for a given active bird object are feeding places, how they catch their food, food - examples and description. Scenario 2 focuses on the sustainable use of ecosystem resources by birds and humans, and level 1 focuses on bird reproduction. The active objects in the level are the selected lake and its specifically selected inhabitants - birds. For each of them, knowledge about: breeding season, nesting sites, pairs, nests, eggs, young, *etc*. is presented in an interactive way.

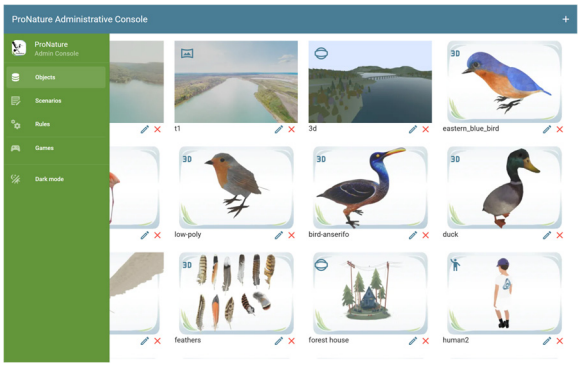

Figure 5: 2D and 3D images of learning objects.

Visualization through 2D and/or 3D images and interactive learning units that teach and test the acquired knowledge are included. Scenario 3 is under development, which aims to raise awareness and knowledge about the protection and care of a protected natural ecosystem (lake), its problems, enemies of the inhabitants, prevention and control of pollution and protection and responses in critical situations of biodiversity and the natural ecosystem, *etc*.

4 THE DESIGN OF THE PRONATURE PLATFORM AND ITS GAME SCENARIO MODULE

A traditional 3-tier architecture was selected for the implementation of the ProNature platform and its components:

- A database layer provisioned by the non-relational database management system MongoDB;
- An application layer, supported by the following technologies: NodeJS, Express, NGINX.
- A presentation layer, based on the web technologies Vue JS, Vuetify and THREE JS, using RESTFul APIs for the communication with the application layer, and thus allowing the system to have multiple presentation layers implemented.

The component diagram (Figure 6) of the game scenario module illustrates how data entities are structured and stored within the database. The ScenarioManager control class is part of the application layer of the platform, responsible for the main logic of the game scenario management. ScenariosManager is a boundary class and manages the communication between the application and presentation layer of the component (it implements the RESTFul API).

All scenario entities will be stored in the non-relational database management system MongoDB using the JSON format. Together with the MVVM (model-view-viewmodel) pattern used for the user interface development, a rapid software development process will be achieved, minimising the needs for data transformations between the layers of the platform.

Despite the logical separation between the components, the front-end design (presentation layer) is planned to be implemented in a way that every feature and functionality will be available for the user (game developer) in a fast and intuitive manner, considering all the good and modern UI/UX practices for a productive game building environment.

5 DISCUSSIONS

The growing global awareness of the issues related to climate change caused a notable rise in the development of serious games focused on the topic (Nabong & Opdyke, 2024). Many of these games are designed to foster an understanding of the causes of climate change and explore effective mitigation strategies relevant to the targeted audiences and contexts. The success of a concrete ProNature serious game depends on three key aspects: gaming-related factors (dimensions), relevant learning theories and principles that should be integrated into the proposed game scenarios (we called them learning-related dimensions), and technical considerations. It is important to carefully evaluate these aspects of the scenarios to ensure they align with the characteristics of the target audience (school students) and the concrete educational context and align with the national educational standards of the school programs.

Learning-related dimensions: The objectives of the ProNature games focused on fostering competence and skills in the responsible management of natural resources and ecosystems, as well as in environmental protection, should align closely with national educational standards and the broader goals of sustainability education. The complexity and format of the content should be appropriately tailored to the target audience of learners, with careful consideration of accessibility and inclusivity.

The scenarios should provide relevant supportive learning resources and learning activities tailored to the student's profile, fostering autonomy and a reward

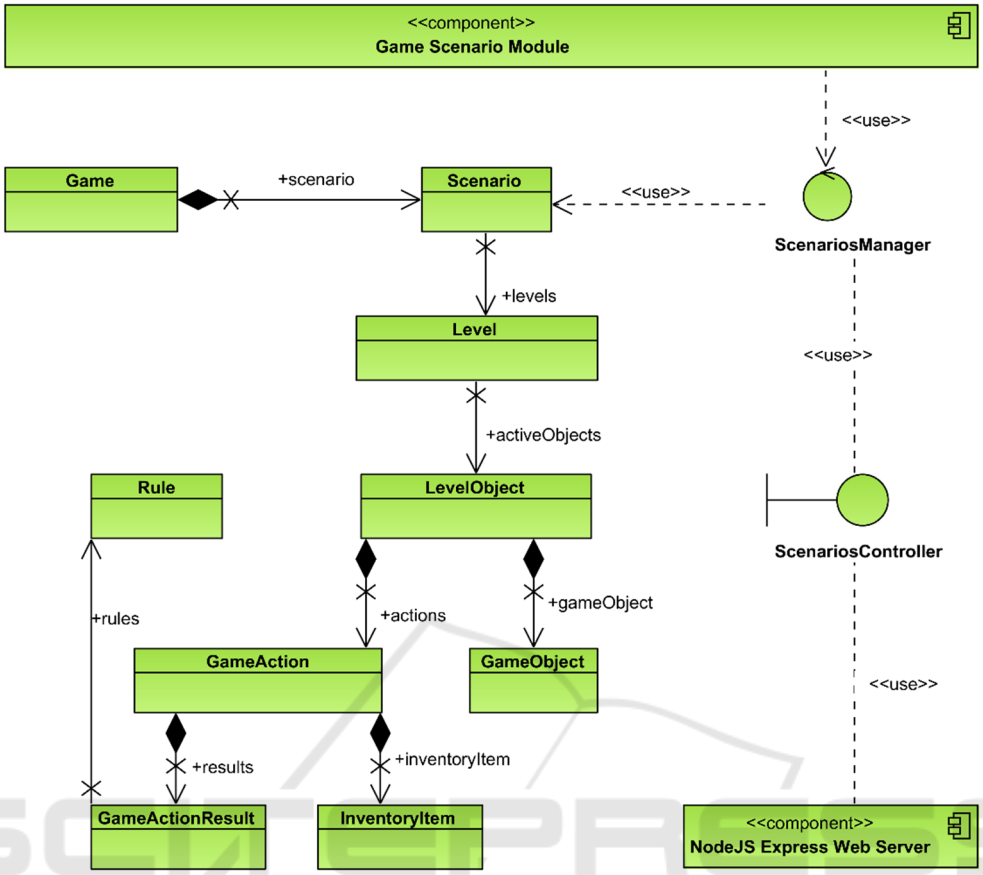

Figure 6: Component diagram of the game scenario module.

system to evaluate player performance. The proposed scenarios should allow the smooth incorporation of the game activities into more complex and comprehensive learning activities encompassing classroom discussions, group work and collaboration, homework assignments, *etc*.

Gaming-related dimensions: The scenarios should contain final objectives and short-term goals to help players achieve the final ones. Players should strive for continuous improvement by gradually increasing the difficulty level without surpassing their capabilities to prevent discouragement. The scenarios have to provide the possibility for players to perceive the impact of their actions enabling behaviour adjustments. Positive feedback, often tied to rewards, enhances engagement, immersion, and goal achievement. The game experience should differ across players and sessions, achieved by adapting challenges to the player's skills and knowledge. The game should captivate a diverse student audience through features such as a compelling narrative, an engaging virtual environment, contextualization, and challenging objectives.

Technical aspects: The game should be based on an intuitive interface and visual elements tailored to the target audience to enhance engagement. All of them need to be specified in detail in the learning scenarios. Moreover, the scenarios should be developed considering the potential for reusing them in different contexts or gaming decors. This will allow teachers to adapt or enhance the scenarios by creating additional levels or adding new learning topics using a user-friendly toolkit.

The proposed framework for scenarios for serious educational games within the ProNature platform demonstrates significant potential, but after the implementation of serious educational games on it, systematic empirical validation of its effectiveness and scalability is yet to be carried out. One of the directions in this regard is user studies to assess engagement, learning outcomes, usability and adaptability in different groups of learners. For instance, pre-test/post-test designs could be employed to measure knowledge acquisition, while control group studies would allow for a comparative analysis of game-based versus traditional learning methods

(Lameras et al., 2021; Nabong & Opdyke, 2024). Additionally, learning analytics and A/B testing could provide insights into the adaptability of the platform, ensuring it meets the needs of learners with varying skill levels and backgrounds (Kamalov et al., 2023; Li & Zhou, 2022).

Another research direction that could influence the development of the ProNature platform is a broader comparison with existing serious educational games. Future research will show whether and how the ProNature platform excels in terms of adaptive difficulty levels and personalized learning paths. For example, while many platforms focus on static content delivery, the ProNature platform's emphasis on creative visualization and dynamic scenario adaptation offers an appropriate approach to fostering environmental awareness and critical thinking (Luchev et al., 2024). This novelty could be further highlighted through comparative studies with platforms like those discussed by De Gloria et al. (2014) and Pellas et al. (2019), which emphasize immersive technologies, but they lack an interdisciplinary focus on environmental education.

Techniques such as facial expression analysis and eye-tracking offer the potential to yield more nuanced insights into emotional engagement, while think-aloud protocols can elucidate cognitive processes occurring during gameplay (Kickmeier-Rust et al., 2011; Kiili et al., 2014; Psaltis et al., 2016; Hookham et al., 2016; Pellicone et al., 2022). However, it is essential to emphasize that apart from the need for specialized analytical expertise, the effective implementation of these engagement studies methods necessitates specialized equipment, which may not be readily available to all participants. This limitation constitutes a significant challenge that warrants further consideration in future research. These methods, combined with self-report surveys and task performance metrics, would offer a comprehensive evaluation of the platform's usability and learning impact (Bijl et al., 2024; Zubair et al., 2024). In general, learning effectiveness studies will assess the improvement in knowledge or skills as a result of playing games on the platform.

Considering these different aspects and choosing appropriate evaluation methods will greatly assist in achieving effective results. The process needs to involve both teachers who have implemented the proposed game-based solutions in their actual work and teaching practices, the learners, as well as experts from educational control bodies. In the project, optimal evaluation methods will be investigated and selected. Future studies should focus on long-term retention tests, demographic-based analyses, and focus groups to ensure the platform's adaptability and inclusivity. By addressing these limitations, the platform can achieve its goal of promoting innovative and sustainable learning experiences.

6 CONCLUSIONS

The presented research and development responds to current trends in creating personalized, inclusive and scalable serious gaming solutions for education that meet different skill levels and goals. The target software platform for serious educational games with creative visualization is in the design and development, but considering each component and its role is essential to the outcomes. This paper focused on learning game scenarios, showing its formalization and development in the ProNature software platform. The consideration of the project concept will continue to evolve to ensure the effective use of the proposed solutions, not only with a view to improving students' understanding of natural ecosystems, but also they will contribute to promoting critical thinking, problem solving and environmental awareness.

Future work will focus on further developing and refining the scenarios in the direction of customization and adaptability, in order to improve the learner's experience and to bring the visual representation as close as possible to the real natural environment. The possibility of reusing already created scenarios, artifact sets, backgrounds and game rules will be expanded, and this will greatly facilitate different developers. They will be able to experiment by combining one game scenario with different artifact sets or rules or using one scenario for different games, *etc*. Collaborative efforts with educators, researchers, and industry stakeholders will be essential to ensure the continued development and widespread adoption of serious educational games as powerful tools for environmental education and sustainable development.

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