Teaching a Serious Game for the Sustainable Development Goals in the Scratch Programming Tool

Irene Kilanioti

Abstract — This work proposes an educational scenario of game-based learning. The scenario is based on a novel serious game, that gets high school students acquainted with the Sustainable Development Goals (SDGs) and promotes the development of their computational thinking skills. Game-based learning is built upon collaborative problem solving and evolves around an interactive story augmented with small quests/inquiries. Students work together to navigate the serious game on the SDGs. As students complete SDGs-related quests/inquiries, the story evolves. The challenge is a game expansion with custom settings (backdrops/avatars) that will take place in Scratch, allowing students to differentiate their learning path. For the game, that was developed in Scratch visual programming environment, this works suggests an educational scenario and indicative student activities for hybrid (synchronous and asynchronous) education. Using the Flipped Classroom instructional strategy, the scenario starts asynchronously, unfolds synchronously, and is completed asynchronously.

The proposed serious game follows the guided discovery method for the acquaintance with the SDGs and the accompanying educational scenario aims for students to acquire the required programming skills to develop a small interactive application on the SDGs. Through game expansion challenge students hone their programming skills in a purposeful and entertaining way. An evaluation by students concludes the work.

Key words — animation, block-based programming, collaborative problem-solving, computational skills, differentiation, game-based learning, quest, inquiry-based learning, interactive story, learning path, purposeful game, Scratch, serious game, sustainability, Sustainable Development Goals, visual programming.

I. INTRODUCTION

Sustainable development signifies enhancement of living standards in the present without compromising future generations’ resources. Sustainable Development Goals (SDGs) were established by the United Nations (UN) in the framework of a 15-year plan, the UN 2030 Agenda, as a quantifiable initiative to safeguard the future for next generations. The collaborative effort to accomplish the goals bears a transformative view of our world and focuses on building a peaceful, equitable society, that will ensure protection of the environment and elimination of hunger and poverty.

The role of students in the achievement of the SDGs is critical. First, they will have to actively participate in conscious selection of future leaders that will commit to sustainability. Most importantly, they will have to express their own opinion on matters that affect children and younger people, explore and debate about the world they imagine for themselves and for coming generations. Acquaintance with the goals and their content is the first step in this direction.

Many studies present e-learning approaches augmented by gamification for knowledge and competencies acquisition, e.g., Rossano et al. [1] propose a Content Management System for digital storytelling augmented with gamification elements to bring knowledge acquisition to fruition. In serious games players are involved in a progressive exposure process that serves a purpose not merely entertaining. Darejeh et al. point out four types of serious games:

1. teaching game, leveraging a game ecosystem to teach a concept;
2. simulator game, imitating a real-world process in a safe virtual environment;
3. meaningful game, conveying a meaningful piece of information;
4. purposeful game, having a daily life impact (e.g., users’ actions or assessment of users’ competencies) [2].

Heretofore, existent digital games on SDGs focus segmentally on a mere goal. To the best of our knowledge, there is not an equivalent digital serious game based on collaborative problem solving, that evolves around an interactive story and is augmented with small quests/ inquirers on all 17 SDGs. Furthermore, the proposed educational scenario has the supplemental purpose of the development of players’ computational skills and leads to differentiated learning paths in the game based on player choices. Purposeful game-based learning is built on Scratch, a visual programming tool, incorporated in international informatics curricula, and can smoothly be integrated into informatics lessons.

Section (II) describes game-based learning and the principles upon which the game was designed and developed by the author. Section (III) presents the structure of the proposed educational scenario. Session (IV) describes an implementation framework for the scenario, including indicative educational activities. Section (V) presents an evaluation of the game based on students’ feedback and Section (VI) discusses the findings. Finally, Section (VII) concludes and discusses the benefits of introduction of the game in educational context and future extensions.

II. GAME-BASED LEARNING

A. Pedagogical Approach & Learning Objectives

The game aims to get students acquainted with SDGs in a fun way, that also drives their learner engagement (edutainment). It aspires to introduce basic concepts and pressing social issues associated with the SDGs (Bloom’s
taxonomy: cognitive level) and subsequently affect life-long behaviors (affective level). The game follows the guided discovery method. Game-based learning is based on collaborative problem solving and evolves around an interactive story augmented with small SDG-related quests/inquiries. Additionally, a scene expansion challenge incentivizes students to attain the required programming competency to develop a small interactive application within the game and promotes the development of their computational thinking skills (Fig. 1). The game was initially targeted at the 12–15 age group in Greece.

Scratch is an event-driven block-based programming language that allows students to understand the concept of interaction among sprites and implement small stories. The satisfaction of creating an interactive story component for the scene expansion challenge motivates students to further expand their programming knowledge. Students will use commands from Scratch Control, Motion and Views collections to add and handle multimedia elements (animations with alternating sprite views/backdrops and with conditionally executed actions, e.g., characters appearing and scenery changing for different phases of the story). Teacher guides and supports students when necessary, creating an exploratory and cooperative learning environment. Assistance should be gradually reduced.

Students team up to navigate the serious game on the SDGs. The story is separated into multiple acts that unfold when SDG-related quests are successfully solved (Fig. 2). Micro-missions help students identify with the game protagonists and relate to the learning objectives through situations that appeal to their values. The adventure consists of SDG-related inquiries, that, once completed, reward the player with experience. Moreover, the teacher should have in advance raised awareness on the SDGs, so that students consciously stay motivated to complete the game.

1. Recommendation mechanism for teaming up students for the game: People-to-people recommendation finds application in online recruitment and other areas where suggestions should, additionally to traditional item-to-people recommendation, promote both reciprocity and positive interaction. In this sense, it differs from unilateral traditional item-to-people recommendation mechanisms. Users’ profiles usually include photo, demographic information, free-text biographical information, psychometric assessments and explicitly declared preferences. The built-in recommendation mechanism for employment is based on the idea of suggesting people to each other based on profile matching or a learned model.

In Online Social Networks (OSNs) recommendation mechanisms for new friends may exploit collaborative filtering techniques or may be rule-based. Clustering techniques are not considered appropriate for people-to-people recommendation due to sparse and time-varying user-preference matrices. Implicit profiles often prove more effective than explicit profiles, and they may furthermore eliminate feelings of rejection among users. Collaborative filtering techniques based on similarity search among user profiles and subsequent ranking of users should be optimized, because issues, such as the excessive suggestion of a few, popular users, arise. Specifically in an educational context, heterogeneous grouping in mixed ability learning settings seems to be beneficial for low achieving students [3], whereas other studies convey equal benefits for all students [4]. Since players are equivalent to learners in the context of serious gaming, aside from ability grouping or grouping based on learner profiles, a potential grouping could leverage various players’ typologies [5–7].

![Game design properties.](image-url)
B. Learning Design

1) Differentiation

Differentiated teaching and learning integrates adaptation of instruction, content, outcomes, and evaluation to address individual learners’ learning needs in the pursuit of an educational goal. In this sense, differentiation may refer to a learning process tailored to various students’ learner profiles in the context of a specific learning sequence and within a well-defined curriculum. Differentiation may as well refer to institutionalized varieties in curriculum: e.g., informatics is mandatory in a subset of German school types and federal states, where the author has worked. Whereas in specific school types of the range of topics spans from automata and regular languages to physical computing, in vocational schools it is restricted to the production of multimedia presentations, creation of professional documents, flyers, letters and excel sheets [8]. Furthermore, differentiation may refer to the way teachers conduct a learning sequence e.g., algorithmic activities without [9] or with technical equipment, with the aid of physical computing, educational tools (Scratch, Greenfoot), etc. Differentiation serves directly the 4th SDG goal (i.e., "ensures inclusive and equitable quality education, promotes lifelong learning opportunities for all" [13]) and is applicable for inclusion either in an explicit [10] or implicit way [11]. Games are based on a learner-centered approach, that differentiates course material in accordance with learner’s selections and favorites. More specifically, the serious game for the SDGs offers following differentiation that makes players feel involved:

a) Choice of device

Students can play the game on mobile devices that support HTML5. The lightweight code for the scene expansion challenge can be edited in mobile devices as well.

b) Learning path

Students can variate the game content in the framework of the game expansion challenge and craft their own path within the game. The path entails a plethora of elements, e.g., backdrops, sounds, music, etc.

2) Feedback and Assessment

a) Feedback mechanism

Generic feedback about correct quiz answers is given within the game in form of messages and retry is possible. For example, in a quiz about SDG1-"No Poverty" concerning elimination of poverty, the multiple-choice question "How many people are living in extreme poverty worldwide?" gives three possible answers ("Around 800 people"/"Around 8.000 people"/"Over 800 million people") [12] and the correct answer (c) is verified, when given. Helpful feedback features and constructive formative feedback through every phase of the game acts through explanations by the protagonists and captions develops self-regulated learners and improves their performance in case they want to replay the game.

b) Assessment

Assessment is based on time and percentage of completion of quests. The challenge is a game expansion with custom settings (backdrops/avatars) that will take place in Scratch, allowing students to differentiate their learning path. It is assessed based on learners’ preferences.

C. Scenario

a) Micro-missions/Quests

Encourage students’ active participation. Quests are based on quiz questions of UN student resources (questions on the SDGs) [12]. Students proceed stepwise following the storyline. For example, when the kids stumble upon something on the beach, they discover it’s a bottle with a map inside. In order to orient the map and reach the island they see on the map; they have to take a boat. Each of the above steps requires solving a small SDG-related quiz. An indicative quest appears in Fig. 2.

Fig. 2. Acts and quests of the game.

b) Learning path

Fig. 3 depicts an indicative learning path with acts and SDG-related quests. Different colours represent different SDG goals in the inquiries, e.g., brown stands for SDG12-"Responsible Consumption and Production", cyan stands for SDG14-"Life below Water", etc.

c) Storyline

A boy and a girl are playing and running on the beach. Suddenly the girl stumbles upon something and discovers the neck of a bottle sticking out. The kids dig the bottle and find out that it contains a map. The kids recognize the island on the map; they are playing by the position of some trees on the beach. The kids reach the bottle and orient the map and they see on the map; they have to take a boat. Each of the above steps requires solving a small SDG-related quiz. An indicative quest appears in Fig. 2.

They see that the map shows a dotted line from the beach ending in a remote island across the sea. The line ends at a vast question mark, that captivates their curiosity, and they are wondering how they could reach this island.

They observe a boat nearby and the boy suggests taking the boat to go to the island. Indeed, they row their boat to the island. However, on their way to the island they feel
their feet wet and realize that the boat is taking on water. The children are terrified, because soon the boat will sink. They notice, however, they have some nice company, two dolphins swimming by the boat. The girl suggests following the dolphins to get them to the island. Indeed, they catch their tails, and, as if the dolphins understood what the children wanted, they brought them almost to the shore.

Tired, the children lie down on the sand and find out that the boat has sunk to the bottom of the sea along with the bottle and its content, the map. While they are thinking what they should do, something like a stone pops up next to them. They find out it is a coconut. Looking up they see a hairy creature on the coconut tree waving its arms menacingly, and they are running away from the shore. The monkey, however, is following them. Suddenly they see a cave and crawl inside to save themselves. The monkey lost them.

Moving forward, they realize they are treading water. At the other end of the cave, they see light, but the water level is rising, so they are forced to dive in order to reach the exit. While swimming, they see a treasure chest on the sea bottom and an octopus guarding it. They open it and see a strange compass inside. They take the compass with the strange symbols in their hands and feel it pulling them towards the exit of the cave. On the way out, however, they encounter a huge jellyfish. Fortunately for them, they see a shadow, which swallows the jellyfish. It was a huge sea turtle. They wasted no time, climbed on the turtle's back, and the magic compass brought them back to the beach where the story started.

When kids reached home, they found out that the compass was glowing. When they told their parents about their adventure and showed them the compass, their father told them that it was golden and that it would tell them where in the world people need their help.

III. EDUCATIONAL SCENARIO STRUCTURE

An educational scenario is proposed to leverage the game in educational context. The scenario concerns hybrid education and entails indicative student activities. Using the Flipped Classroom instructional strategy, the scenario starts asynchronously, unfolds synchronously, and is completed asynchronously. The course has been created in the eclass platform, a digital environment for learning, communication, and collaboration, supporting various teaching scenarios and tools. All the eclass tools used to implement the scenario are active for the students, who are already familiar with their use. Students are also familiar with the Webex environment as well as with some of the basic Scratch features (offline editor, online version) and ScratchJr for mobile devices.

For the connection with the prior knowledge of the objectives of sustainable development (for which students can play the game next and, moreover, add/reengineer scenes themselves), UN student material can be used. The question material for the quests is drawn from this [12].

Additional UN student material on the SDGs that can be used is associated with an interactive climate learning toolkit, activities designed to assist students in introducing the core concepts of what it means to be a global citizen (empathy, fairness, social development, equality, understanding consequences of behavior), a playbook to help young people make choices less harmful for the environment, etc. [13].

IV. IMPLEMENTATION FRAMEWORK OF THE EDUCATIONAL SCENARIO

A. Objective

Students will work together to play the first scenes of the game. They will team up and develop a customized scene within the game. As a learning outcome, students will acquire competencies associated with the SDGs and further
develop their critical computational, and algorithmic thinking (through understanding the operation of programming components and basic structures of the visual, event-driven programming tool Scratch). Fig. 4 outlines the scenario.

Prerequisite students’ knowledge and competencies for the implementation of the scenario: The scenario is targeted at the 12–15 age group, who have some familiarity with the Scratch environment. In particular, they should already know how to create simple programs that are executed by clicking the green flag, and the basic motion, control and wait commands. Implementation time: 1 teaching hour (30 min.) synchronous and 2 hours (60 min.) asynchronous distance learning.

Used tools: 1. Webex. Share content, Breakout sessions, Polling, Whiteboard, Reactions, Chat, Participants (change role). 2. eclass: Quiz, Documents, Tasks, Learning line, Learning statistics, Messages, Wall, Chat, Multimedia, Links. Other Tools: Scratch visual programming environment (offline editor and online tool), ScratchJr for mobile device. The lesson plan is described in detail in Fig. 5 along with the specific activities and the media used.

![Diagram of workflow](image-url)

**Fig. 4. Workflow of hybrid educational scenario.**

B. Phase 1 (Asynchronous)

For the connection with the prior knowledge of the objectives of sustainable development, introductory UN student material is provided as a link collection in the eclass platform. Eclass is a digital environment for learning, communication, and collaboration, supporting various teaching scenarios and tools. Supplementary UN student resources on the SDGs that can be used are associated with 170 Actions (a set of 10 daily suggestions for each goal) to transform our everyday life, the story of a young girl, Frieda, in Namibia, that simplifies the lessons of the SDGs, an interactive climate learning toolkit, a free online educational trivia game that triggers real financial donations to the World Food Programme, etc. [13].

The previous lesson of the informatics course concerned an exercise with letters that dance/rotate/change color, etc. In this phase, students are asked to answer questions in the eclass platform related to Scratch views, adding sound, waiting and the basic structures of selection and repetition (e.g., in sprites’ motion). Students will use the eclass:Quiz named Scratch_quiz. Then through the eclass:L ink students will view an example of a story in Scratch. The video is about creating a script for a story/fairy tale and relates functions known to students to the creation of the script, e.g., to change scenery, show/hide a character and synchronized dialogues between characters. Alternatively, the specific video can be downloaded as a file that will be included in the eclass:Multimedia category.

Finally, from the eclass:Documents option, the file "Instructions to make a story in Scratch.pdf", a document with detailed instructions on the scene expansion challenge that gives guidance on the necessary steps to implement a Scratch interactive story, will be opened.

C. Phase 2 (Synchronous)

This phase explores first students’ prerepresentations. Students are invited to interact in the Webex platform through the Whiteboard annotate functionality and display in a brainstorming activity their main impressions from the video they watched and the instructions they read.

In a collaborative learning activity students build teams and play together the first scenes of the game. Some examples of indicative multiple-choice SDG quizzes are given:

1. SDG4-"Quality Education" "Education…
   a) Will make it hard for you to get a job
   b) Will help you get a job and improve your life
   c) Is only useful for very smart kids”,

2. SDG6-"Clean Water and Sanitation” "Where does most of the wastewater resulting from human activities go?
   a) It is treated and recycled
   b) It is stored in safe places
   c) It is discharged into rivers or seas without any treatment against pollution”,

3. SDG16-"Peace, Justice and Strong Institutions” “What is a refugee camp?
   a) A summer camp in the mountains
   b) A camp for the protection of people when they flee from their homes
   c) A military camp” [12].

Subsequently, students are divided up into groups through Webex:Breakout sessions to tackle the programming challenge associated with completing/modifying the story as a team. They are challenged to modify/augment/add a scene in a common project (peer instruction).
When returning to the plenary session, the group representatives are invited to present their proposal for achieving the challenge they worked on as presenters. The rest of the students comment on both the scene content and correctness of the generated code using Webex:Reactions or via Webex:Chat. The meeting is completed when, through Webex:Polling, students individually express their personal opinion by selecting the proposal they prefer to expand the story. This ensures student participation and interactivity during the lesson module and makes students feel appreciated and challenged.

It is not mandatory for the students to incorporate in the story all the steps described in the guide. Each group can deal with different steps from the guide (2 steps from the pdf file for each group suffice). Steps: Add backgrounds and figures/Make your figures talk/Change backgrounds/Add sound or effects to your figure/Move the figure/Make the figure appear on stage (including resizing the figure)/Respond to a figure (synchronization with messages).

D. Phase 3 (Asynchronous)

Students are again invited to form groups in the eclass platform (eclass:User Groups) in order to solve a problem of greater extent, similar to that of the synchronous phase, and to interact with each other asynchronously. They can modify or enhance the already existing story to a greater extent or create a supplementary scene, shuffle quizzes, etc. Students can work locally on their device with the offline Scratch editor or use the online software and ScratchJr for portable/mobile devices.

Through the tools eclass:Chat, eclass:Messages they can exchange information and opinions. On the eclass:Wall students are invited to display their suggestions regarding the challenge. Actively documenting and elaborating on shared gaming and programming experiences will provide social drivers for students to gain their peer recognition and
will enhance their performance in the long term. A moderated forum or discussion board within eclass or other tool, where students are encouraged to post and share game tips, can prove useful as well.

E. Phase 4 (Asynchronous)

Eventually, students are invited to complete a self-assessment activity through a Scratch quiz as well as an evaluation of the course through a Likert scale survey (eclass:Likert scale).

To support the self-assessment, a sequence named "Scratch_stories" was created through the eclass:Learning line tool, in which students can immerse themselves in activities sequentially, following each step according to the lesson design. At the same time, statistical data about the course can be displayed through the eclass:Learning statistics tool, in order to highlight the progress of the students in the specific subject.

V. EVALUATION

An initial evaluation was conducted among 25 students of a high school class in Attica, so that the impact of the proposed serious game could be measured. The evaluation was conducted via a digital questionnaire based on serious games evaluation bibliography [14]–[16] and took place after applying the proposed educational scenario. Detailed instructions were given to the students for all phases. There follow the questions of the questionnaire:

1. Do you think the game is moderate in terms of difficulty?
2. Did you find the scene expansion challenge exciting?
3. Does the game associate goals with acts and combine fun with realism?
4. Did you like the gameplay?
5. Would you like to see visual markers, e.g., leaderboard and badges for achievements?
6. Would you like a dynamic scenario for multiple plays?
7. Do you think that the game achieved its objectives?
8. Will you apply your newly acquired knowledge in daily life?
9. Do you think the storyline is compelling and not functionally restrictive?
10. Did you like the flexibility in reengineering scenes and quests, and would you like to see a game expansion pack?

The questions can be divided in three broad categories: feedback and personalization (Q2, Q5, Q6, Q10), gameplay (Q1, Q4, Q9), objectives and realism (Q3, Q7, Q8). The results of the evaluation are depicted in Fig. 6–15. Additionally, students suggested in the open-ended questions that more difficult quests should be rewarded with an "easter egg", namely an extra game feature or surprise.

The findings indicated a welcoming attitude of the students towards the game and suggest its further use for a worth mentionable impact. Based on the evaluation data students can further interact in the framework of the educational scenario with the jigsaw strategy, becoming experts on specific game elements in rotation and sharing their knowledge with their fellow learners.
VI. DISCUSSION

The statistical analysis (Q2, Q5, Q6, Q10) suggests that the game should be extended with additional personalized feedback. This reinforces the notion that SDG-related recommendations are individually tailored to the students. Aside from existent points and scores, leaderboards with students who have completed all acts, a recognition for the effort of highest-scoring students, personalized reward elements, badges, milestones, and progress bars for students’ achievements along their learning path would further motivate them [17], [18]. Ideally, dynamic scenarios adapting on gamer selections through various acts would reinforce the notion of self-regulation in the game [19].

Summing up the gaming experience evaluation (Q3, Q7, Q8), aside from being ready to incorporate relevant digital activities into their lesson, teachers should encourage students to transfer their learning about sustainable development into daily life. Teachers could suggest daily opportunities for students to transfer into the real-world what they have learned in the serious game, e.g., by amplifying their participation in the local community, reusing items for crafting, recycling, transferring the acquired knowledge to their friends, adding their voice against disparities and inequalities, shopping smart, practicing and promoting good sanitary habits, turning electric appliances off, when they do not need them, planting a tree, growing their vegetables in their own backyard, staying informed, etc.

Moreover, evaluation of the serious game’s partner selection mechanism for the improvement of the gameplay is important (Q1, Q4). An optimized selection of partners.
within the context of the proposed game-based learning is applicable on a larger scale, i.e., when a substantial number of online participants concurrently plays the game. It consists of the following components:

1. Interaction mechanism: could include chatting, commenting on the same resource, assigning tag on a resource, belonging to the same group, etc. All these actions take place in the tools described in the educational scenario.

2. Semantic module: combines specific SDG term with emotional disposition of player towards partner within chat or other interaction with a specific partner.

3. Sentiment analysis: can be generic (positive, negative, neutral characterization) or exploit a specific affect space [20] augmented with specific traits of the in-game messaging domain. Abbreviations, emoticons, acronyms, exclamations marks etc. may be indicative of the user emotional disposition towards his/her interlocutor. Sentiment analysis can be used to understand emotion in opinionated user generated content. However, existent domain-specific machine learning approaches for sentiment analysis cannot be directly applied to in-game messaging since they are trained on labelled data.

4. Aggregation module: combines all interactions with semantic connotation for a specific user and calculates a cumulative score per user. Users with the highest score of points in this aggregation should be paired together.

VII. CONCLUSION

This work proposes an educational scenario based on a digital serious game that gets high school students acquainted with the Sustainable Development Goals (SDGs). Besides, the proposed educational scenario has the supplemental purpose of the development of players’ computational skills. The scenario leads to differentiated learning paths in the game based on player choices, allowing students to craft their own paths to the learning objectives. The game is built on Scratch, a visual programming tool, incorporated in international informatics curricula, and can smoothly be integrated into informatics lessons.

Taking into consideration that young people’s active participation for the accomplishment of a sustainable future is critical and that achievement of sustainability will definitely be in the hands of the younger generation in the long term, raising awareness on sustainable practices in the present should definitely be incorporated in school curricula. This work aspires to contribute to this direction.

REFERENCES


I. Kilanioti was born in Athens and has been working as Teaching Laboratory Staff at National Technical University of Athens, School of Electrical and Computer Engineering, since September 2021. She has been a PostDoc Researcher with Forschungsgruppe Data Mining in der Medizin, Ludwig-Maximilian-Universität in Munich (2018–2020) and use case reporter for Chipset cost action IC1406. She received her PhD entitled “Improving Content Delivery with OSN-Awareness” from the Department of Computer Science, University of Cyprus, in 2017 and was granted the Greek State Scholarships Foundation scholarship during years 2012–2015. She holds a BSc. and MSc. (best student award) from Department of Informatics and Telecommunications of the National Kapodistrian University of Athens and a Diploma in Translation from Institute of Linguists, London. She has worked as an informatics teacher since 2005 (in Greece, Germany), as a software engineer and teaching assistant in tertiary education. She has completed two-year studies for the licensure (Lehramt) for german high schools (Gymnasien) at Friedrich-Alexander-Universität in Erlangen.

DOI: http://dx.doi.org/10.24018/ejeng.2022.1.2957

December 2022.