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Experiences with a Serious Game Introducing Basic Knowledge About Renewable Energy Technologies: A Practical Implementation in a German Secondary School

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Abstract

In this article, we describe a practical implementation of a serious game to facilitate knowledge acquisition about renewable energy technologies among youngsters, using the game Serena Supergreen and the Broken Blade. We present the quest design and an evaluation study on the research questions: (a) Did youngsters who played the game have more knowledge about renewable energy technologies compared to those who did not play the game? (b) How did students perceive the game? (c) What did the students recall from the game 11 months after playing it? The study was conducted at a German secondary school (n = 82). Youngsters who played the game had more knowledge on renewable energy technologies compared to the control group (n = 31). In a second round of data collection,

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11 months after playing, a majority of students still remembered the game quests. Our results indicate that serious games are a promising approach for introducing basic knowledge about renewable energy technologies.

Keywords: Sustainable development goals, serious games, technical knowledge, renewable energy technologies, vocational education training

INTRODUCTION

Sustainable development has been recognized worldwide as an urgent topic. In short, sustainable development is to satisfy the needs of all living beings of the present without compromising the needs of future generations (World Commission on Environment and Development, 1987). This basic assumption of security supply for the world population and future generations is found in the 1987 report of the World Commission on Environment and Development, titled *Our Common Future* (ibid.). In 2014, the United Nation started the 'Decade of Sustainable Energy for All' with the goal to promote the use of sustainable energy to reduce gas emissions to limit climate warming. Renewable energies are ascribed as being central for sustainable development to prevent climate change and contributing to other goals such as gender equality, sustainable communities or climate protection (United Nations Development Program, 2016). Deployment of renewable energies and improvement of energy efficiency are essential to achieve this goal (IEA et al., 2019).

The question of how to educate youngsters for sustainable development has been discussed for over a decade (Barth et al., 2007, 2010; de Haan, 2010; Kopnina, 2020; Leicht et al., 2018; Sauvé, 1996; Singer-Brodowski, 2017). The United Nations, Educational, Scientific and Cultural Organization (UNESCO) addresses the urgent need for an Education for Sustainable Development (ESD) to enable people to 'think and work towards a sustainable future' (United Nations, Educational, Scientific and Cultural Organization [UNESCO], 2019, p. 1). Besides different skills and competency concepts (Barth et al., 2007; de Haan, 2006, 2010; Glasser & Hirsch, 2016), Sustainable Development Goals (SDGs; UNESCO, 2017), alternative didactical approaches such as eco-pedagogy or self-empowerment (Kahn, 2002), transformative learning (Riekmann, 2018) or action-oriented learning (Pauw et al., 2015) as well as a critical examination of those concepts have been suggested and discussed (Kopnina, 2020; Wals & Jickling, 2002).

De Haan (2007) refers to knowledge as a starting point to act on sustainable development. Rieckmann (2018) points out that knowledge next to skills should be the foundation of ESD combined with attitudes, values and behaviour. Knowledge about renewable energy technology can be necessary to become an active member in decision-making processes towards a sustainable energy supply (Jorgenson et al., 2019). Basic knowledge about renewable energy technology is relevant for youngsters to understand the role in the energy mix and the impact of individual energy consumption. Despite this relevance, as Jorgenson et al. (2019) argue, renewable energy technologies are not yet sufficiently addressed in school.

In recent years, research on digital serious games as an educational tool in the various fields of sustainable development has received attention (Janakiraman et al., 2018; Katsaliaki & Mustafee, 2015; Medema et al., 2019). Furthermore, advantages and effects of digital serious games for learning by implementing learning objectives in a playful and motivating environment have been discussed widely (Boyle et al., 2016; Braghirolli et al., 2016; Connolly et al., 2012; Dörner et al., 2016; Iten & Petko, 2016; Kapp et al., 2019; Plass et al., 2015; Wouters & van Oostendorp, 2017; Wouters et al., 2013). Serious games differ from conventional games in that a specific learning goal is formulated at the development stage and considered during game design to achieve a measurable outcome (Dörner et al., 2016; Plass et al., 2015).

In this article, we will describe the design and practical implementation of a serious game to facilitate knowledge about renewable energy technologies and interest in related professions, the serious game Serena Supergreen and the Broken Blade. In the adventure game, the player has to solve several technical tasks regarding renewable energies. Game quests contain technical details of renewable energies, about their basic functionality, how to repair them and how they relate to everyday life. The game has been developed as a pedagogical tool for students aged 12 to 16. Didactical material allows either to implement the game in school subjects or use it as extracurricular activity. We also present an evaluation study experiment with 82 students of a German secondary school who played the digital serious game Serena Supergreen and the Broken Blade. In the study, we investigated the research questions: (a) Did youngsters who played the game have more knowledge about renewable energy technologies compared to those who did not play the game? (b) How did students perceive the game? (c) What did students recall from the game 11 months after playing it? Based on this example, we will discuss practical implications of a serious game as an introductory activity in the context of ESD goals.

CURRENT ROLE OF RENEWABLE ENERGY TECHNOLOGIES IN FORMAL EDUCATION

Basic knowledge on technical development for sustainable energy supply is mandatory to follow the current discussion about future energy supply as an active member of a society (Jorgenson et al., 2019). Renewable energy technologies are a key factor of sustainable development (Frank et al., 2017; IEA et al., 2019; World Commission on Environment and Development, 1987), also described by the formulation of SDG number 7 'Affordable and Clean Energy' (United Nations, 2017). Wind energy, photovoltaics, biomass, hydropower and more are just a few examples of the variety and complexity of renewable energy technologies (Frank et al., 2017). Without the appropriate knowledge about renewable energies, the evaluation of and participation in decision-making processes concerning this matter can be difficult. A recent literature review on energy education stated that there is a lack of engagement with energy systems in education at school (Jorgenson et al., 2019). The authors argue that to stimulate a transition towards a renewable-based energy system, youngsters should gain knowledge of technical developments to participate in this sector, and even to promote career interest. Thus, educating youngsters about renewable energy technologies should be one important part of sustainable development. Knowledge can serve as a solid foundation to understand and evaluate decisions on technological research and development. Youngsters should be able to critically reflect experts' opinions on different forms of energy supply.

But how are renewable energy technologies addressed in schools so far? In German school curricula, renewable energy technologies are not mandatory. Screening curricula of German class levels 7 to 10 (age 12–15) in 2017, renewable energies are not a central topic of the curricula in physics, biology, chemistry, science, economics and labour, technology or geography in any of the 16 German federal states. Renewable energy technology is not described as a separate learning area on its own right. If mentioned, then it appears as a subitem. For instance, in the area of energy production, renewable energy is referred to in its relevance for society, but not in its technological aspects. Another example can be found in the curriculum in the state of Saxony. In the field of solar power, there is no technological divergence with the topic of solar technology, as there is no anchoring of solar technology (Saxony Ministry of State for Kultus, 2019). Solar power is mentioned as a subitem of physics lessons at secondary school in the learning area of 'types and principles of power plants'. A screening of extracurricular activities has also shown that the implementation of solar panels on school roofs gives reason to deal with the topic. This way, further physical relationships (effects of serial and parallel connection) can be worked out by measuring the current intensity and voltage. But as described above, this approach is rather implemented in extracurricular activities than in school contexts.

Since renewable energies have only a very small significance in German curricula until 10th grade, it is hardly possible to work out technical details in the classroom. There is rarely room to understand the function of different kinds of renewable energies or to take a look at specific components. On the one hand, the community widely agrees that knowledge about renewable energy and underlying technologies is essential to participate in future decision-making regarding energy transition; on the other hand, introducing renewable energy technologies in school is not mandatory so far. Especially since the topic can be very complex, target group-oriented approaches are necessary to introduce relevant knowledge in school.

SERIOUS GAMES AS EDUCATIONAL TOOLS FOR LEARNING ABOUT RENEWABLE ENERGY TECHNOLOGIES

Technical development has created new opportunities for learning. As one example, digital serious games have been discussed as educational tool. The term digital serious game refers to digital games that not only serve entertainment purposes '… but use the entertaining quality for training, education, health, public policy, and strategic communication objectives' (Wouters et al., 2013, p. 250). Serious games are interactive, based on defined rules, have a clear goal and give feedback to the players (Dörner et al., 2016). Digital serious games can engage learners interactively in a target group-oriented virtual environment. Digital serious games also have the advantage of developing a digital and entertaining learning environment, which is appealing to a specific target group due to its well-designed story, graphic illustrations or further game-mechanics such as a narrative, avatars, pedagogical agents or sound in line with a certain target-group's characteristic or needs (Plass et al., 2015). They also can have advantages for learning within a classroom setting, such as solving tasks at an individual pace, experiencing content in a secure space and exploring scenarios or settings that would not be possible in the classroom context. Also, games are associated with a sense of autonomy and therefore increased self-efficacy, as players can make self-determined decisions and experience the consequences of their actions in the game environment (Klimmt, 2006).

Positive results on learning, motivation, knowledge and engagement have been found in previous studies (Boyle et al., 2016; Braghirolli et al., 2016; Connolly et al., 2012; Iten & Petko, 2016; Kapp et al., 2019; Plass et al., 2015; Wouters et al., 2013, 2017). Plass et al. (2015) describe four main functions of digital serious games to achieve different objectives and output in the context of learning: the preparation of future learning, teaching of new knowledge and skills, practising and reinforcing already existing knowledge and skills and the development of 21st-century skills. The authors argue that digital games provide the opportunity not only to practise but also to apply knowledge repeatedly in different game quests, and, by that, 'facilitate the abstractions needed for knowledge to be generalized to novel situations' (p. 266). Regarding knowledge acquisition through playing a serious game, Wouters et al. (2013) state that 'serious games lead to well-structured prior knowledge on which learners can build on during their learning career' (p. 260). For instance, in a study in the field of industrial engineering, Braghirolli et al. (2016) found out that using a serious game as introductory activity can foster motivation and understanding of the course content.

Linking serious games with the concept of sustainable development has become more popular. In recent years, the number of digital games dealing with sustainable development in the context of education has increased (Fabricatore & Lopez, 2012; Janakiraman et al., 2018; Katsaliaki & Mustafee, 2015). Using terms such as Games for Change or Social Impact Games, some games are dedicated to make a contribution to sustainable development (Games for Change, 2020; Games for Sustainability, 2020).

For instance, in the field of collaborative water governance, the potential of serious games has been described as an instrument to see the bigger picture of complexity or as a way to enhance reflection on difficult situations (Medema et al., 2019). However, Morganti et al. (2017) state that reliable research results on educational games for pro-environmental attitudes or behaviour are scarce. The authors conducted an analysis on reliable research papers in the field of educational games for energy efficiency. Screening 241 non-duplicate citations using web of science and scopus, the authors came to the result that only 10 papers met their full criteria, such as impact of the applied game on users or infrastructures. They identified three game areas: environmental education, consumption awareness and energy efficiency behaviour. In the field of environmental education, only two games were part of the selection: the games Trash War and Enercities. Bardhan and Bahuman (2016) evaluated the web-based serious game Trash War on the effects on the intent creation for waste segregation behaviour. The player receives points for putting trash into the correct trash bin. The authors found that the children mostly lacked information on differences between recyclable and reusable waste. Knol and de Vries (2011) evaluated the web-based serious game Enercities to examine if participants who played the game had a greater environmental and energy awareness as well as a more positive attitude compared to those who did not play the game. The authors found significant differences on both variables, attitude and awareness concerning energy efficiency. Another study on the game Powersaver about energy conservation in the household by Fijnheer et al. (2018) showed an increase in knowledge after playing a game compared to using an energy dashboard with the same content. The authors argue that the increase in knowledge could lead to energy saving behaviour in the long term. A lot of studies are aiming at pro-environmental attitudes or pro-environmental behaviour; however, more research is necessary on the role of games in sustainability education (Janakiraman et al., 2018).

AIM OF THE STUDY

Serious games have proven to foster knowledge acquisition and motivation during learning. Thus, they are a promising tool for ESD. One approach to use them in this context is to introduce basic knowledge about renewable energy technologies within a game and take the game experience as a starting point for further learning activities in the classroom.

The aim of this article is twofold: (a) to introduce the serious game Serena Supergreen and the Broken Blade. The serious game for youngsters at German secondary school level addresses basic knowledge about wind power, solar energy and energy saving. It has been developed within a research project funded by the German Federal Ministry of Education and Research under Grant 01PD17005 which investigated, amongst other research topics, the potential of serious games for gender-sensitive career choice (Kapp et al., 2019; Spangenberger et al., 2018). In the first section of the article, the game and the development of technology-related quest is described in order to get an insight on how a specific game for ESD can look like.

(b) The second aim is to present findings from the evaluation of the serious game addressing the following research questions: (i) Did youngsters who played the game have more knowledge about renewable energy technologies compared to those who did not play the game? (ii) How did students perceive the game? (iii) What did students recall from the game 11 months after playing it? The findings of an empirical study are presented in the second section of the article.

Finally, based on our example, we will discuss practical implications and to what extent a serious game can be used as an introductory activity for teaching renewable energy and basics about the underlying technology.

SERENA SUPERGREEN AND THE BROKEN BLADE

The serious game Serena Supergreen and the Broken Blade is a point-and-click-adventure about the character Serena, who masters technical tasks to save enough money to go on a vacation together with her friends. The game addresses learning objectives regarding affordable and clean energy (SDG 7) by learning about different

Figure 1 In-game Screenshots Showing Serena and Her Friends in the Final Level on an Island (on the Left), and, Showing the Changing of a Light Bulb in a Pet Shop (on the Right)

Source: The good Evil/Serena project.

forms of sustainable energy supply and its technical usage (UNESCO, 2017). The main learning objective of the game was to foster mastering of technical quests, especially for female players (SDG 5) (see also Kapp et al., 2019). While solving the quests, the player receives feedback by so called non-player-characters to support mastering the quests self-regulated. The technology-related quests contain information about light-emitting diodes (LEDs), Lumen and power, solar power, solar heat, wind power, electro mobility and energy saving (see Figure 1).

The game lasts about 3 to 4 hours. In the first level, the player is briefly introduced to how to play the game. As a point-and-click adventure, the player operates by pointing at things or directions, then clicking on them, and, by doing so, moving the avatar or letting him interact with the objects of the game environment. In the second level, the player learns about the main goal of the adventure. Serena has to earn enough money to go on a holiday trip together with her best friends, Kiki and Myra. Serena can use a virtual smartphone to write text messages with her friends during the entire game. As a first task, she has to prepare a job application to work at the mall. While collecting all necessary items for the application, the light turns off, and she has to fix the lighting. The second level continues in the mall, where Serena works in a pet shop and has to solve several quests in the field of LEDs, Lumen and power to increase the pets' well-being. After successfully solving the tasks in the pet shop, more technical challenges are to be solved in different shops at the mall, such as a repair-café, an outdoor shop and a music store. After earning enough money, the player and her two friends end up on an island lacking electricity and heat generation. In this final level of the adventure game, different components of sustainable energy consumption and technical functionality of renewable energies are implemented in the quest design. Serena has to build on her previous technology-related experiences during the game and has to repair power distribution, a wind power plant and a solar power plant on the roof of a house.

In the beginning of the game, the technology-related quests are of low difficulty, such as changing lighting or selecting the appropriate lamp socket. By advancing within the game story, quests become more difficult, and previous expertise has to be applied on advanced quests repeatedly. Six different learning contents are addressed: (a) LED, Lumen and power, (b) solar heat, (c) solar power, (d) wind power,

(e) electro mobility and (f) energy saving. For instance, in the beginning of the game, players have to repair a pump (wind power). They learn how to use a screwdriver. In the next quest regarding wind power, they have to print a gear wheel and learn about relevant parameters, followed by a quest on safety instructions for climbing. In the next quest, they learn how to repair a ventilation system. Building on this knowledge, players have to climb on a wind power plant to fix the gearbox and rotor blade of a wind power plant in the final level (see Table 1).

Table 1 Game Quests in the Field Wind Power as They Appear in the Game

Learning content	Quests (as they appear in game)	Technical tasks
Wind power	Repair of a pump	• Sales order: Troubleshooting • Mechanical repair (screwdrivers)
Wind power	Make gearwheel for ventilation system on 3D printer	• Selection of the right component (shape) • Determination of the correct parameters • Selection of the material
Wind power	Safety techniques at height	• Abseiling, climbing • Using safety technology (helmet, climbing harness, descender device)
Wind power	Error analysis and repair of a mechanical system (ventilation system)	• Determination of error noises, finding the cause of error: Defective gearwheel • Tool selection • Comply with protective measures • Disassembly of the gear wheel, gear measurement • Assembly of the gear wheel • Function test after successful repair
Wind power	Safety techniques at height	• Abseiling • Use a safety technology (helmet, climbing harness, descender device) • Teamwork
Wind power	Troubleshooting the blade of a wind turbine	• Locate a hole in the blade of the wind turbine • Apply the working steps for the repair of a rotor blade (sanding, gluing, painting) • Work with adhesives (know the connection between resin and hardener) • Function test/commissioning
Wind power	Gearbox repair	• Gearbox repairing (analyse the error and find a suitable solution) • Recognizing functional structure of gear unit • Replace a rolling bearing by using the properties of the workpiece (heat influence—expansion of metals) • Compliance with occupational safety (protective gloves)

Source: Illustrated and structured by authors.

By this approach of using and applying knowledge, the player is mastering about 18 technical quests during the course of the game. The degree of difficulty was determined in close consultation with the target group. In a previous study on gender effects of the game using a different sample, it has been shown that this approach can foster girls' self-efficacy in solving technical tasks (Kapp et al., 2019; Spangenberger et al., 2018). Solving a quest opens up new quests, while collecting necessary items in a backpack and continuing with the story about Serena and her plan to go on vacation with her friends.

EVALUATION STUDY

The second aim of this article is to present findings on the following research questions: (a) Did youngsters who played the game have more knowledge about renewable energy technologies compared to those who did not play the game? (b) How did students perceive the game? (c) What did students recall from the game 11 months after playing it?

Participants and Design

Eighty-two students from a secondary school participated in the study. Fifty-one students played the game and 31 students served as control group who had regular school lessons. The participants were students age 12 to 14 ($M = 13.6$, $SD = 0.639$). Forty-two students who played the game responded to a follow-up questionnaire after 11 months ($N = 42$, $M = 14.28$, $SD = 0.733$).

Measures

To evaluate knowledge acquisition by using a serious game, Mayer et al. (2014) recommend using a test prepared as an exam, giving scores for each correct answer after completing the game. Thus, a test was conducted containing 12 items, which were designed based on content taught in the game. It addressed the topics LED, Lumen and power (3 items), solar heat, (1 item), solar power (2 items), wind power (3 items) and electro mobility (1 item), energy saving (2). Participants were asked to recall declarative knowledge, describe procedures and mark relevant components of technical systems in a picture. A score system counted correct answers (see Table 2). The possible maximum amount of points was 25 points, if all answers were answered correctly. All tests were scored by two researchers. The interrater reliability scores were consistent to a degree of 0.97 (intraclass correlation coefficient = 0.992).

In order to assess students' perceptions and experiences during the gameplay, a German game experience scale (Klimmt, 2006) was used. It contained 15 items regarding the perceived experience (e.g., 'I felt relaxed', 'I felt challenged by playing the game', 'I was not satisfied by playing the game'; Likert scale 1 = strongly disagree to 5 = strongly agree; Cronbach's alpha = 0.924).

In the follow-up questionnaire that was administered after 11 months, students were asked to answer the open question: 'Which quests did you play? Please describe quests you had to solve!' To analyse the open answers a quantitative content analysis

Table 2 Knowledge Test About Game-related Content

No.	Item	Scoring of item	Total
1	How do you change a light source?	• Disconnect power supply (light switch off and/or fuse off) (1 point) • Screw a new lamp into the socket (1 point) • Reconnect power supply (1 point)	3
2	Why does a fuse pop out?	• In an overload condition (when too many consumers are connected to one circuit) (1 point)	1
3	Please explain Lumen	• Lumen is the standardized unit for the so-called luminous flux and allows conclusions to be drawn about the brightness of a lamp (1 point) • The light bulb needs more watt than an LED for the same amount of Lumen (1 point)	2
4	Which of the three light sources (light bulb, LED or energy saving lamp) emits the least heat?	1 point for correct choice of illustration (LED)	1
5	Which of the three light sources (light bulb, LED or energy saving lamp) shines the brightest?	1 point for correct choice of illustration (LED)	1
6	Which country has the most electric vehicles per inhabitant?	Norway (1 point)	1
7	On which of the two pictures you can see a lustre terminal. Mark the lustre terminal with a cross. (X)!	1 point for correct mark	1
8	Which device checks if there's electricity? Mark with a cross. (X)	1 point for correct mark	1
9	Mark the solder in the upper picture with a circle (o)!	1 point for correct mark	1
10	How do you proceed if you want to test the functionality of a solar cell?	• For the functionality of a solar charger, the (open circuit) voltages of the solar (break) cells are relevant (1 point) • For the measurement you use a multimetre (1 point) • The red measuring tip of the measuring instrument is held against the back of the solar cell ([+] pole) and the black measuring tip against the front ([–]pole).	7

		• (1 point) for naming the measuring points on the front and rear side • (1 point) for the correct designation of the sides as (+)pole and (–) pole • (1 point) for the statement that the suitable measuring tip (suitable 'colour') must be assigned to the poles • (1 point) for correct assignment red (+)pole and black (–)pole • (1 point) the multimetre must be set to DC voltage	
11	What can be seen on the following picture?	Solar cooker (1 point)	1
12	The picture shows a wind turbine. Name the individual parts of the wind power plant. Mark the element with a circle and then connect it with a dash to the respective term.	Maximum of 5 points, if all parts have been marked correctly	5

Source: Illustrated and structured by authors.

approach (Mayring, 2014) was used and answers were coded in alignment with the six game content categories: (a) LED, Lumen and power, (b) solar heat, (c) solar power, (d) wind power, (e) electro mobility and (f) energy saving.

Procedure

The investigation was conducted over a period of two weeks. All students were informed that they are taking part in a study to develop and give feedback for a game for their age group. On day one of the intervention, each student who was supposed to play the game was given a tablet. In the following two hours, the students started playing the game in class. After that, they were instructed by their teacher to finish the game during the next two weeks. One researcher was at the school periodically to fix technical problems, if they occurred. After the two weeks, students handed back the tablets and were asked to fill out two different questionnaires. A control group did not play the game and filled out the same questionnaires before and after the investigation. Students were questioned with regard to their perceived entertainment, knowledge and socio-demographic data. After 11 months, one researcher went back to the school and distributed questionnaires. Students who played the game were questioned again regarding their memory of the quest content (n = 42). To analyse the differences between the control group and the group who played the game, an independent t-test was used. To measure the relationship between knowledge and game experience, Pearson's correlation coefficient was calculated. And, to calculate results, the software SPSS was used.

RESULTS

Knowledge and Game Experience

On average, students playing the game scored higher in the knowledge test (M = 9.62, SD = 2.53, n = 48) than those who did not play the game (M = 5.03, SD = 3.87, n = 30). This difference was significant t(76)=-5.76, p=0.000, d=1.33.

On average, students who played the game perceived it as a positive experience (M = 2.34, SD = 0.76, n = 49). There was a significant relationship between entertainment of the game and the scores achieved in the knowledge test, Pearson´s r = 0.31, BCa CI {0.079, 0.528}, p = 0.031.

Recall of the Game Quests After 11 Months

Students' levels of recall of the game quests were measured after 11 months by asking them to answer the open question 'Which quests did you play? Please describe quests you had to solve!' The answers were categorized with regard to the six learning areas (LED, Lumen and power, solar heat, solar power, wind power, electro mobility and energy saving). In sum, 31 out of 42 participants (73.8%) reported that they had to repair something in the game. Furthermore, 27 of the participants (62.3%)

Table 3 Frequencies of Recalled Quests by Participants After 11 Months Since Playing the Game, Presented in Total and Selected by the Level of Game Experience

Category	Quest	Frequency in total (*n* = 42) (%)	Negative experience (*n* = 13) (%)	Positive experience (*n* = 29) (%)
LED, Lumen and power	Repair or replace a defective light source	18 (42.9)	3 (7.1)	15 (35.7)
LED, Lumen and power	Switch on/off a fuse	4 (9.5)	1 (2.4)	3 (7.1)
Solar heat	Connect solar modules on the roof	6 (14.3)	1 (2.4)	5 (11.9)
Solar power	Solder a solar charger	12 (28.8)	1 (2.4)	11 (26.2)
Wind power	Repair a wind energy plant	15 (35.7)	2 (4.8)	13 (31.0)
Wind power	Repair a ventilation	7 (16.6)	0 (0)	7 (16.6)
Electro mobility	Charge an electro-battery	5 (11.9)	1 (2.4)	4 (9.5)
Electro mobility	Master a quiz on electro mobility	3 (7.1)	0 (0)	3 (7.1)
Energy saving	Connecting power supply	4 (9.5)	0 (0)	4 (9.5)

Source: Illustrated and structured by authors.

were able to recall specific quests in the field of renewable energy technology, while 6 participants (14.3%) did not remember any quests. As shown by the frequency distribution in Table 3, the quests mentioned most frequently were in the category LED, Lumen and power, followed by wind power and solar heat.

DISCUSSION AND LIMITATIONS

The presented study investigated the three research questions: (a) Did youngsters who played the game have more knowledge about renewable energy technologies compared to those who did not play the game? (b) How did students perceive the game? (c) What did students recall from the game 11 months after playing it? Participants of the study were students of a secondary school in Germany, who played the serious game Serena Supergreen and the Broken Blade. Knowledge acquisition of students who played the game was compared to a control group who did not play the game. Youngsters who played the game were also questioned 11 months afterwards to investigate their memory of the quests. The test on knowledge acquisition showed that the students who played the game scored higher than the control group who did not play the game. It was also found that students' perceptions and experiences during the game were positively correlated with their knowledge acquisition. Additionally, 62.3 per cent of students could recall specific quest content on renewable energy technologies 11 months after playing the game. Those students who reported a positive experience while playing in the first study were able to recall more quests in the long term, compared to students who reported a more negative experience of the game.

Thus, we assume that the entertaining story of the game supported facilitation of knowledge. For the study, a beta version of the game Serena Supergreen and the Broken Blade was used, which still had a few technical problems. Some students were complaining about bugs during the intervention. Technical support was available one week after the tablets had been handed out. This might have affected game experience. It can be assumed that without the technical defects of the beta version, the players' perceived game experience might have been different (eventually more positive) and, by that, could have influenced the results of the knowledge test.

The results are limited by the fact that only a small number of participants took part in the study. There was no evaluation of knowledge on renewable energy technologies prior to playing the game. Instead, a focus group workshop was conducted to examine the level of information on renewable energy technologies of youngsters at the same school one year prior to the study, showing that there was a lack of knowledge on renewable energy technologies. This information informed the game design (see also Kapp et al., 2019). In future studies, knowledge should be tested before playing the game as well as being tested in the long term.

A majority of the students were able to remember specific game quests of Serena Supergreen and the Broken Blade 11 months after playing the game. Since the game was not available at that time, it can be assumed that students had not played the game repeatedly after our intervention. It was a surprising observation that students could describe specific game quests even 11 months later. The acquired knowledge of students can be a starting point for future learning. There is still a lack of reliable findings on a game´s long-term impact regarding sustainable development (Janakiraman et al., 2018). And, in future research, long-term memory of a game on knowledge acquisition in the field of renewable energies should be investigated by using a different test design. It would also be of interest to examine if remembered content can be applied or built on in a learning setting at school. As Kerres et al. (2009) point out, the reflection of a game experience can be an important factor for the learning process.

IMPLICATIONS FOR EDUCATION FOR SUSTAINABLE DEVELOPMENT GOALS

In this article, we introduced a serious game that focuses on the learning objectives of SDG 7 (affordable and clean energy) and SDG 5 (gender equality). We focused on the question of how a serious game has to be designed to contribute to facilitate knowledge acquisition about renewable energy technologies, which are a relevant factor for sustainable development. The learning objective informed the game and quest design. Quests contained technology-based knowledge about solar panels, wind power plants, energy saving, electro mobility and LED, Lumen and light to introduce facts and at the same time skills about repairs. Students who played the game perceived it as a positive experience and were actively involved in mastering tasks regarding renewable energy technologies. Players had to actively apply knowledge to solve problems in an interactive environment by learning how to repair renewable energy-related technical tasks. Thus, playing Serena Supergreen and the Broken Blade can support the idea of Rieckmann (2018), who argues that education for sustainability would be in need of an 'action-oriented transformative pedagogy' containing a learner-centred approach and action-oriented learning. Furthermore, the story was developed in participation with the main target group of girls aged 12 to 16 to close the gap between renewable energy technologies as an abstract form of energy supply and youngsters' daily needs. Educators could use this game experience to further engage students in a discussion about their own experiences and views on renewable energy technologies, energy efficiency or energy consumption. Game designers might consider the learning objectives of ESD Goals as formulated by the UNESCO in 2017, when designing a game that should contribute to sustainable development. To sum up, the advantages of serious games for ESD goals are as follows,

- specific learning objectives of an SDGs (see UNESCO, 2017) can inform game mechanics (narrative, quests, genre, sound, aesthetics),
- target group preferences and daily needs can be considered,
- actions are directly visible,
- players can be confronted with the outcome of their actions,
- tasks can be repeatedly trained, and,
- learning outcome is measurable.

However, ethical aspects should also be considered depending on the chosen SDG as well as the limits of distribution of a serious game. A serious game wants to reach an audience. Thus, it needs teachers who implement the game in the school. Moreover, technological equipment is necessary to make it accessible for students. Last but not least, school equipment can vary between countries and even between schools of the same country.

CONCLUSION

In alignment with Jorgenson et al. (2019), knowledge on renewable energy technologies should be introduced in school to foster engagement for sustainable development. In this article, it has been shown that using a serious game can be a promising approach to introduce knowledge about renewable energy technologies among youngsters. Using the example of the serious game Serena Supegreen and the Broken Blade, we presented a serious game that provides real-life experiences regarding SDGs that cannot be easily implemented or realized at school. Based on our results, introducing new knowledge about renewable energy technologies by implementing this knowledge in an entertaining point-and-click adventure seems to be a promising approach within a classroom setting. Exploring tasks on a low level in the beginning, to build on them in more advanced quests later in the game, provided the opportunity to apply the technology-related knowledge directly in the game environment.

The potential of serious games has been recognized in ESD, and more well-designed serious games can be expected in the near future. By describing our experiences within this article, we hope to contribute to that discussion and give a deeper insight into the development and complexity of the design and practical implementation of a digital serious game in school that contributes to the SDGs.

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References

Bardhan, R., Bahuman, C., Pathan, I., & Ramamritham, K. (2016). Designing a game based persuasive technology to promote pro-environmental behaviour (PEB). In Institute of Electrical and Electronics Engineers (Chair), *2015 IEEE Region 10 Humanitarian Technology Conference (R10-HTC).* Cebu City, Philippines.

Barth, M., Godemann, J., Rieckmann, M., & Stoltenberg, U. (2007). Developing key competencies for sustainable development in higher education. *International Journal of Sustainability in Higher Education*, *8*(4), 416–430. https://doi.org/10.1108/14676370710823582

Barth, M., Michelsen, G., & Sanusi, Z. A. (2011). A review on higher Education for Sustainable Development: Looking back and moving forward. *Journal of Social Sciences*, *7*(1), 100–103. https://doi.org/10.3844/jssp.2011.100.103

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Ribeiro, C., & Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education*, *94*(94), 178–192. https://doi.org/10.1016/j.compedu.2015.11.003

Braghirolli, L. F., Ribeiro, J. L. D., Weise, A. D., & Pizzolato, M. (2016). Benefits of educational games as an introductory activity in industrial engineering education. *Computers in Human Behavior*, *58*, 315–324. https://doi.org/10.1016/j.chb.2015.12.063

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. https://doi.org/10.1016/j.compedu.2012.03.004

De Haan, G. (2010). The development of ESD-related competencies in supportive institutional frameworks. *International Review of Education*, *56*(2–3), 315–328. https://doi.org/10.1007/s11159-010-9157-9

Dörner, R., Göbel, S., Effelsberg, W., & Wiemeyer, J. (Eds.) (2016). *Serious games: Foundations, concepts and practice*. Springer.

Fabricatore, C., & Lopez, X. (2012). Sustainability learning through gaming: An exploratory study. *Electronic Journal of e-Learning*, *10*(2), 209–222.

Fijnheer, J. D. L., van Oostendorp, H., & Veltkamp, R. C. (2019). Enhancing energy conservation by a household energy game. In M. Gentile, M. Allegra, & H. Söbke (Eds.), *Information systems and applications, incl. Internet/Web, and HCI—Games and Learning Alliance: 7th*

International Conference, GALA 2018, Palermo, Italy, December 5–7, 2018, Proceedings (Vol. 11385, pp. 257–266). Springer International Publishing. https://doi.org/10.1007/978-3-030-11548-7_24

Frank, O., Fischer, T., Dorfinger, P., Prawatky, L., Simstich, Y., Westphal, M., Triantafyllos, V., & Asmelash, E. (2017, December). *Status and perspectives for renewable energy development in the UNECE region*. Deutsche Energie-Agentur GmbH (dena).

Games for Change. (2020). http://www.gamesforchange.org/games/

Games for Sustainability. (2020). https://gamesforsustainability.org/

Glasser, H., & Hirsch, J. (2016). Toward the development of robust learning for sustainability core competencies. *Sustainability: The Journal of Record*, *9*(3), 121–134. https://doi.org/10.1089/sus.2016.29054.hg

IEA, IRENA, UNSD, WB, & WHO (2019). Tracking SDG 7: The energy progress report 2019.

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. https://doi.org/10.1111/bjet.12226

Janakiraman, S., Watson, S. L., & Watson, W. R. (2018). Using game-based learning to facilitate attitude change for environmental sustainability. *Journal of Education for Sustainable Development*, *12*(2), 176–185. https://doi.org/10.1177/0973408218783286

Jorgenson, S. N., Stephens, J. C., & White, B. (2019). Environmental education in transition: A critical review of recent research on climate change and energy education. *The Journal of Environmental Education*, *50*(3), 160–171. https://doi.org/10.1080/00958964.2019.1604478

Kahn, R. V. (2010). *Critical pedagogy, ecoliteracy, & planetary crisis: The ecopedagogy movement*. *Counterpoints: Vol. 359*. Lang.

Kapp, F., Spangenberger, P., Kruse, L., & Narciss, S. (2019). Investigating changes in self-evaluation of technical competences in the serious game Serena Supergreen: Findings, challenges and lessons learned. *Metacognition Learning*, *14*(3), 387–411. https://doi.org/10.1007/s11409-019-09209-4

Katsaliaki, K., & Mustafee, N. (2015). Edutainment for sustainable development. *Simulation & Gaming*, *46*(6), 647–672. https://doi.org/10.1177/1046878114552166

Kerres, M., Bormann, M., & Vervenne, M. (2009). Didaktische Konzeption von Serious Games: Zur Verknüpfung von Spiel- und Lernangeboten. *Zeitschrift Für Theorie Und Praxis Der Medienbildung*, 1–16. https://doi.org/10.21240/mpaed/00/2009.08.25.X

Klimmt, C. (2006). *Computerspielen als Handlung. Dimensionen und Determinanten des Erlebens interaktiver Unterhaltungsangebote*. Herbert von Halem Verlag.

Knol, E., & de Vries, P. W. (2011). Enercities: Educational Game about Energy. In *CESB 10 Prague: Central Europe towards sustainable building from theory to practice* (pp. 1–4). CESB.

Kopnina, H. (2020). Education for the future? Critical evaluation of Education for Sustainable Development goals. *The Journal of Environmental Education*, *22*(1), 1–12. https://doi.org/10.1080/00958964.2019.1710444

Leicht, A., Heiss, J., & Byun, W. J. (Eds.). (2018). *Education on the move*. *Issues and trends in Education for Sustainable Development*. United Nations Educational, Scientific and Cultural Organization.

Mayer, I., Bekebrede, G., Harteveld, C., Warmelink, H., Zhou, Q., van Ruijven, T., Lo, J., Kortmann, R., & Wenzler, I. (2014). The research and evaluation of serious games: Toward a comprehensive methodology. *British Journal of Educational Technology*, *45*(3), 502–527. https://doi.org/10.1111/bjet.12067

Mayring, P. (2014). *Qualitative content analysis: Theoretical foundation, basic procedures and software solution*. http://nbn-resolving.de/urn:nbn:de:0168-ssoar-395173

Medema, W., Mayer, I., Adamowski, J., Wals, A. E. J., & Chew, C. (2019). The potential of serious games to solve water problems: Editorial to the special issue on game-based approaches to sustainable water governance. *Water*, *11*(12), 2562. https://doi.org/10.3390/w11122562

Morganti, L., Pallavicini, F., Cadel, E., Candelieri, A., Archetti, F., & Mantovani, F. (2017). Gaming for Earth: Serious games and gamification to engage consumers in pro-environmental behaviours for energy efficiency. *Energy Research & Social Science*, *29*, 95–102. https://doi.org/10.1016/j.erss.2017.05.001

Pauw, J., Gericke, N., Olsson, D., & Berglund, T. (2015). The effectiveness of Education for Sustainable Development. *Sustainability*, *7*(11), 15693–15717. https://doi.org/10.3390/su71115693

Plass, J. L., Homer, B. D., & Kinzer, C. K. (2015). Foundations of game-based learning. *Educational Psychologist*, *50*(4), 258–283. https://doi.org/10.1080/00461520.2015.1122533

Rieckmann, M. (2018). Learning to transform the world: Key competencies in ESD. In A. Leicht, J. Heiss, & W. J. Byun (Eds.), *Education on the move: Issues and trends in Education for Sustainable Development* (pp. 39–59). United Nations Educational, Scientific and Cultural Organization.

Sauvé, L. (1996). Environmental education and sustainable development: A further appraisal. *Canadian Journal of Environmental Education*, *1*(Spring), 7–34. https://eric.ed.gov/?id=EJ540073

Saxony Ministry of State for Kultus (Ed.). (2019). *Lehrplan Oberschule Wirtschaft-Technik-Haushalt/Soziales*. [Curricula secondary school, economics, technology, social aspects].

Singer-Brodowski, M. (2017). Pedagogical content knowledge of sustainability: A missing piece in the puzzle of professional development of educators in higher Education for Sustainable Development. *International Journal of Sustainability in Higher Education*, *18*(6), 841–856. https://doi.org/10.1108/IJSHE-02-2016-0035

Spangenberger, P., Kapp, F., Kurse, L., Hartmann, M., & Narciss, S. (2018). How to attract girls for technology professions by playing a serious game? *International Journal of Gender, Science and Technology* (IJGST), *10*(2), 253–264. http://genderandset.open.ac.uk/index.php/genderandset/article/view/496/952

Spangenberger, P., Kapp, F., Kruse, L., Hartmann, M., & Narciss, S. (2018). Can a serious game attract girls to technology professions? *International Journal of Gender, Science and Technology, 10*(2), 253–264. Retrieved from http://genderandset.open.ac.uk/index.php/genderandset/article/view/496/952

United Nations Development Programme. (2016). *Delivering Sustainable Energy in a Changing Climate: Strategy Note on Sustainable Energy 2017–2021*. New York.

United Nations, Educational, Scientific and Cultural Organization (UNESCO). (2017). *Education for Sustainable Development goals: Learning objectives (2017)*.

United Nations, Educational, Scientific and Cultural Organization (UNESCO). (2019). *Education for sustainable development*. https://en.unesco.org/themes/education-sustainable-development

Wals, A. E. J., & Jickling, B. (2002). 'Sustainability' in higher education: From doublethink and newspeak to critical thinking and meaningful learning. *International Journal of Sustainability in Higher Education*, *3*(3), 221–232. https://doi.org/10.1108/14676370210434688

Wouters, P., van Nimwegen, C., van Oostendorp, H., & van der Spek, E. D. (2013). A meta-analysis of the cognitive and motivational effects of serious games. *Journal of Educational Psychology*, *105*(2), 249–265. https://doi.org/10.1037/a0031311

Wouters, P., & van Oostendorp, H. (Eds.). (2017). *Advances in game-based learning: Techniques to improve the effectiveness of serious games*. Springer.

World Commission on Environment and Development. (1987). *Our common future*. Oxford University Press.