Serious Games in Secondary Education to Introduce Circular Economy: Experiences With the Game EcoCEO

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The concept of the circular economy is being proposed as an alternative for the current linear economy. However, little research has been done on how to integrate this topic within education. Serious games are suggested as an appropriate way to create awareness about and stimulate behavioral change toward sustainable development. Therefore, the serious game ecoCEO has been developed to introduce the circular economy concept within upper secondary education. The game's intention is to introduce students to the challenge of resource scarcity, circular product design, sustainable entrepreneurship and circular business models. EcoCEO has been tested among 42 students, whose written reflections were qualitatively examined. EcoCEO appears successful, at least partially, in contrasting the circular economy with the linear economy and in conveying relevant concepts such as recycling and reuse. EcoCEO also illustrates the importance of the circular economy within the context of material scarcity. Moreover, most students in our case study seem to have a good impression of the role and responsibilities of a (sustainable) entrepreneur. Despite its difficulty level, the majority of the students reported having fun while playing ecoCEO.

Keywords: serious games, circular economy, education for sustainable development, entrepreneurial education, game based learning, secondary education

INTRODUCTION

Circular economy is gaining interest among businesses, academia and policymakers (Geissdoerfer et al., 2017). The linear "take-make-sell-dispose" model is losing ground as a consequence of the increasing depletion of finite resources (Suárez-Eiroa et al., 2019). Therefore, the cradle-to-cradle concept was introduced by McDonough and Braungart (2002), followed by the concept of the circular economy which gained popularity thanks to the work of the Ellen MacArthur Foundation (2013). Various studies tried to define this concept of the circular economy (Kirchherr et al., 2017; Korhonen et al., 2018). However, within the business world the Ellen MacArthur Foundation leads the debate on the circular economy being referred to as "based on the principles of designing out waste and pollution, keeping products and materials in use and regenerating natural systems" (Ellen MacArthur Foundation, 2021).

Despite the increasing importance of the circular economy, research efforts on how to integrate this topic in education are still limited (Whalen et al., 2018) and mainly aimed at higher education (Kirchherr and Piscicelli, 2019; Mendoza et al., 2019). Similarly, although the broader topic of education for sustainable development is more widely studied, the focus is also aimed at higher education (Wu and Shen, 2016), management education (Figueiró and Raufflet, 2015; Gatti et al., 2019), business education (Andersson, 2016) or design education (Leube and Walcher, 2017). While the development of circular economy solutions requires technological innovations, business models as well as supporting policies (Ghisellini et al., 2016), it is widely acknowledged that behavioral change and consumer acceptance are crucial elements of a successful, society-wide implementation (Camacho-Otero et al., 2018; Parajuly et al., 2020). The engagement of the wider public, and especially of young adults and students, is key in order to induce a societal mindshift toward more circular behaviors such as longer use, reuse and repair, advocating the need for tailored awareness building and education targeted toward younger age groups (Korsunova et al., 2021). Several organizations and funded international projects have developed educational materials about circular economy aimed at primary and secondary schools, including downloadable lesson plans, instruction movies and class activities (The Ellen MacArthur Foundation, 2017; The Finnish Innovation Fund Sitra, 2019; João, 2020; Foundation for Environmental Education, 2021). Still, research about suitable approaches to introduce circular economy concepts in secondary education is largely lacking as in most of the case studies higher education is the focus like for example in Kopnina (2018) and Bugallo-Rodríguez and Vega-Marcote (2020). In this paper, we want to contribute to filling this gap.

Education plays a crucial role in supporting sustainability and sustainable development (Shephard, 2008). However, teaching about sustainability is a challenging endeavor, since the topic is complex and integrates many disciplines, while teacher-directed teaching methods are not very engaging and do not suffice to encourage behavioral change (Chappin et al., 2017). Teaching methods that step away from this traditional knowledge-focused and discipline-centered approach embracing a broader perspective of system thinking can help students to better grasp and consider the various aspects, trade-offs, interdependencies, casualties and different stakeholder perspectives of sustainable development (Hiller Connell et al., 2012). When students master system thinking, they will be able to view cause, consequence and possible solutions in a holistic manner including environmental, social and economic aspects (Whalen et al., 2018). Moreover, most of the adopted teaching methods focus on cognitive learning outcomes such as knowledge and skills, whereas in sustainability education affective learning outcomes in terms of values, attitudes and behavior are central. The latter are achieved more effectively using appropriate role models in sustainability education (Shephard, 2008).

Educational (or serious) games are gaining attention as attractive and effective tools to create awareness and promoting behavioral change related to sustainability. As described by Stapleton (2004) and Breuer and Bente (2010), serious games are games that transcend the purpose of entertainment and in which education is the primary goal. The learning does not need to be explicit—it can also be achieved indirectly—and can take the form of knowledge production, the development of skills, or provide a change in behavior (Southgate et al., 2017). In general, serious games are classified in different genres such as strategy games, simulation games, action games and so on based on their narrative design and core mechanics (Ke, 2016). Hence, the integration of serious sustainability games in curricula can help motivate students to become change agents for a more sustainable society (Dieleman and Huisingh, 2006).

There is a growing market for serious games (Susi et al., 2007) and an increasing interest in serious games in academic research (Breuer and Bente, 2010). Despite the rising interest from the academic field, research about the experiences and effectiveness of serious games is limited. Nonetheless, there is increasing evidence that serious games positively affect students' motivation, engagement, and learning outcomes. The positive effect is however dependent on the choice of a suitable serious game for the specific class, among others (Southgate et al., 2017). Moreover, Amorim et al. (2014) showed that students prefer new teaching methods above teacher-directed lectures. Teachers, on the other hand, are looking for new (digital) tools to support their lessons (Southgate et al., 2017). Such games require the student to adapt to changing game situations as well as to develop and use their problem-solving skills (Southgate et al., 2017). In a teacher-directed classroom setting the teacher plays the central role and has full control over all activities. In serious games the locus of control lies with the student deciding what to do, when to do it, what the goals are, etc. In this way, serious games create an authentic, meaningful, and rich learning environment (Breuer and Bente, 2010). While playing, students are challenged to take their own decisions and to develop diverse skills and strategies to achieve the goal of the game in a pleasant way (Stapleton, 2004; Bevilacqua et al., 2015) or to find solutions for the unexpected circumstances they face during play, triggering reflection and critical thinking (Ouariachi et al., 2018). In that sense, serious games give a stimulus for active learning (Amorim et al., 2014). The gained knowledge, the knowledge production processes, and the complex problem-solving processes will not only be remembered better but also promptly applied in other situations. In that sense, the visual factor plays an important didactic role (Amorim et al., 2014). Also, the perceived fun factor of games serves as an important motivator for students to engage in educational games (Ibrahim et al., 2011).

However, learning through a serious game is more complex (Southgate et al., 2017) and teachers, especially the ones who did not learn actively themself, are more reluctant to use serious games (Amorim et al., 2014). Other pitfalls related to the use of serious game described in the literature are among others the time span to play the game, the purchase price of the game, reconciling the game with the curriculum, the way the serious games have to be used, the lack of information about the serious game etc (Ulicsak and Williamson, 2010; Southgate et al., 2017; Chen, 2021). Furthermore, specific competences and a mix of managerial and technical competencies are required from teachers for facilitating serious games in higher education (Hauge

TABLE 1 | Game mechanics and related thinking skills in the ecoCEO game.

Game mechanics	Representation in the game	Thinking skills (Bloom's classification)
Strategy/planning	Applying a dedicated business strategy is are rewarded, as awards are granted for logical investment combinations.	Creating
Worker placement	During each turn, workers are dedicated to the available company activities.	
Turn taking	Players takes clockwise turns.	Evaluating
Action points	A turn includes three potential actions: (1) Invest, (2) Assign workers, (3) Sell products.	
Resource management	A limited amount of resource cards are available to manufacture products with.	
Rewards/penalties	Events cards emerge, disrupting the flow of the game. Awards are granted for logical investment combinations.	
Feedback	Feedback on the business strategies applied is foreseen in the debriefing.	Analyzing
Card drawing	During the mining activity cards are drawn from the central deck. These serve a dual function as resource and investment opportunity.	Applying
Victory points	Investments made, awards received and revenues generated translate into victory points, determining the winner.	
Role play	Players are in the shoes of the CEO of an electronics company.	Understanding

et al., 2021). Teachers also mention that not all students can make a link between the play of the game and the learning goals (Southgate et al., 2017). To achieve better learning results, games should be supplemented with other instruction methods, such as group discussion as it supports learners in articulating their insights to their peers, resulting in a more profound anchoring and integration of the new knowledge with prior knowledge (Wouters et al., 2013). Furthermore, Caserman et al. (2020) identified in their research a set of quality criteria in order to meet the double goal of a serious game, i.e., simultaneous achievement of intended effects and entertainment. Their quality criteria are: (1) clear goals, (2) focus on the characterizing goal, (3) indispensability of the characterizing goal, (4) correctness of the domain expert content, (5) appropriate feedback on progress, (6) appropriate rewards, (7) proof of effectiveness and (8) use of game awards or ratings. Furthermore, De la Torre et al. (2021) describes specific characteristics to make serious games useful to teach about the circular economy and sustainable energy. Important elements besides their research are a high level of realism, implementing consideration of multiple aspects at once in each game decision so that players recognize the non-linearity of their decision-making process and covering all stages of the circular economy.

Various serious games have been developed addressing sustainability challenges such as the energy transition (Ouariachi et al., 2018), competition for finite resources (Chappin et al., 2017), water management (Rusca et al., 2012) and many other sustainability issues (Madani et al., 2017; Stanitsas et al., 2019). Research has been done on how these educational games can improve understanding of sustainability challenges (Madani et al., 2017; Stanitsas et al., 2019) and induce behavioral change (Chappin et al., 2017). Also, in the field of circular economy, a few educational games have been developed recently (Whalen, 2017; Sofies Group, 2018; Whalen et al., 2018). However, these games are primarily designed for use in higher education and by professionals, and are not

adapted to be used in high schools in terms of complexity or cost.

To respond to the need of secondary school teachers for engaging learning materials that address grand societal challenges, such as the transition to a circular economy, the serious game ecoCEO was created for 16–18-year-olds. The purpose of this paper is to describe the learning outcomes of ecoCEO with respect to circular economy and (sustainable) entrepreneurship on the one hand, and the game play experience on the other hand, using a qualitative approach. Although the design of the game is beyond the scope of this article, its intended learning goals and course of play are explained in Game based learning with ecoCEO. In Materials and methods we describe the context in which the game was played and the way in which its experience is evaluated. Therefore, evaluation criteria have been identified as a basis for a qualitative document study of student reflection reports. The evaluation results are reported and illustrated extensively with citations from the reflection reports in Results. The findings per evaluation criterion are summarized and discussed in Discussion, whereas the sixth and final section concludes on the game experience of ecoCEO.

GAME BASED LEARNING WITH EcoCEO

EcoCEO is a downloadable game that aims to increase awareness and transfer knowledge about circular economy strategies and sustainable entrepreneurship to students in upper secondary education (students of 16–18 years old). The game is multiplayer and competitive, played with 3 or 4 players, individually or in teams of two players. A game session, including introduction, explanation of game rules, game setup and debriefing, takes 90–100 min in total (i.e., the average duration of two standard classes). The game materials are in English. An overview of the included game mechanics and related thinking skills is provided in **Table 1**, based on Bloom's taxonomy for educational learning and Suttie et al. (2012).

TABLE 2 | Linear economy strategies in the ecoCEO game.

Linear economy principles	Representation in the game
Mining of virgin resources	Drawing resource cards from the central raw materials pile
Production	Producing microchips/smartphones/e-bikes with the resource cards at hand
Product sales	Selling microchips/smartphones/e-bikes to the central market for money
Resource efficiency	Producing microchips/smartphones/e-bikes with one resource less
Resource substitution	Replacing one resource for another when producing a microchip/smartphone/e-bike

TABLE 3 | Circular economy strategies in the ecoCEO game.

Circular economy principles	Representation in the game
Waste recycling	Reclaiming resource cards from the central waste pile as an alternative for mining virgin resources
Take back and sell for scrap	Taking back microchips/smartphones/e-bikes from the central market and selling it to the central waste pile for a credit
Microchip reuse	Reusing the microchip from products taken back from the central market in new products
Renting service	Renting out products instead of selling them, in exchange for a recurrent rental fee
Design for repair	Allowing for rented out products to be repaired so they continue to yield credits

The Course of Play

During the game, players run a company that produces electronic products, such as microchips, smartphones and e-bikes. Their mission is to develop a thriving business. They need to make decisions about their investment strategy, worker allocation and materials management. By combining different investments, they can diversify their product portfolio, improve their production efficiency and try new business models to maximize their company's performance and profitability. Across the game, day-to-day business is interrupted by event cards representing regulatory changes or market challenges, such as government tax, a ban on toxic materials or a change in market prices.

The game consists of two stages. During stage I, players learn about the production and sales processes in a linear economy, based on the traditional take-make-sell-dispose pattern. They learn how efficiency measures and resource substitution strategies can optimize this system in response to resource constraints. **Table 2** provides an overview of how the linear economy principles were integrated in the game.

Stage II introduces the circular economy, in which new, circular business models can help overcome resource constraints.

Table 3 provides an overview of the circular economy principles represented in the game.

The game ends after 60 min of play. Each company's success is measured in victory points that can be gained through strategic investments, awards and the accumulation of revenues. The player or team with the most victory points wins the game.

After gameplay, the teacher leads a debriefing session to engage students in a group discussion about the impact of sustainable business strategies, consumption patterns, resource scarcity and waste management on the financial performance and resilience of a company (**Figure 1**).

MATERIALS AND METHODS

The aim of this research is to investigate the students' game experiences and to explore whether the serious game ecoCEO succeeds in achieving its learning objectives, i.e., (1) understanding the principles behind the linear and circular economy and (2) reflecting on the activities of a (sustainable) entrepreneur. This research takes a qualitative approach entailing a document study of written reflection reports of students who played the game (Flick, 2018), which is a similar approach as was used in other research on game-based learning (e.g., Whalen et al., 2018). Convenience sampling was used to select the participating schools. The teachers and the participating school gave their explicit consent to participate in the research. The game was played in three different class groups ($n1 = 16$, $n2 = 12$, $n3 = 14$) in secondary schools in Flanders, Belgium. Two groups consisted of economics students, while the third group was a mixed group of students from different study programs, who followed a seminar class on circular economy. All students had Dutch as their mother tongue. At the moment of the play, students' prior knowledge about the topic was limited to waste and waste recycling as these are the only topics mentioned related to circular economy in the curriculum of primary education and the first two degrees of secondary education in Flanders, Belgium. Other aspects of the circular economy are introduced in the last degree of secondary education. As this study was conducted in the beginning of the academic year, the students were not familiar with these concepts yet (Vlaams Ministerie van Onderwijs en Vorming, z.d.-a, z.d.-b, z.d.-c, z.d.-d).

Every game workshop started with a short introduction. Students were asked about the lifespan of their smartphone, the fate of their old smartphones, how smartphones are recycled, how many raw materials are used and what –if any- prior knowledge they had about the circular economy. Overall the majority of the students were not familiar with the concept of the circular economy before the start of the serious game. The introduction was followed by an explanation of the ecoCEO game rules with the help of instruction videos in English. In school 1 the teacher was already familiar with the game ecoCEO. Therefore, the game was led by the teacher and the researcher in a co-teaching setting. In schools 2 and 3, the game was led by the researcher only, using an instruction PowerPoint and the instruction videos in English.

After playing the game, a short debriefing session of 5 to 10 min was held to reflect with the class group to discuss which
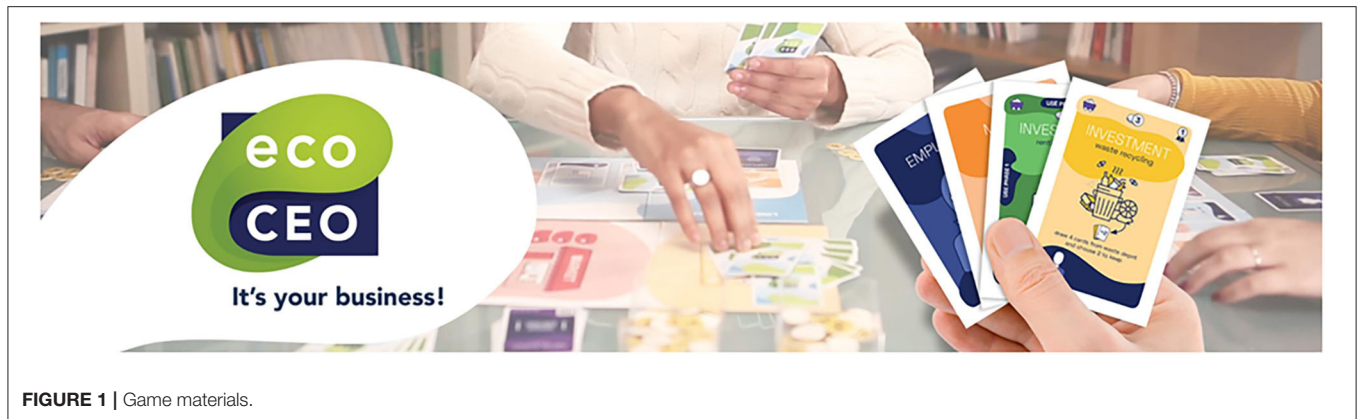
FIGURE 1 | Game materials.

TABLE 4 | Information class groups.

Educational institution	School 1	School 2	School 3
Study programme	Business economics	Business economics	Mixed group (seminar circular economy)
Grade	5th year	6th year	5th and 6th year
Number of students	16	12	14
Instruction	Instruction videos Co-teaching with 2 teachers	Instruction videos and an instruction-PowerPoint No co-teaching	Instruction videos and an instruction-PowerPoint No co-teaching
Type of data collection	Reflection report based on guiding questions	Reflection report based on two open questions	Reflection report based on two open questions
Grading of the report	Graded	Not graded	Not graded

challenges the students were confronted with, which strategies they used and which choices had to be made when running a business. In all three class groups the debriefing was led by the teacher. Finally, students were asked one week after playing the game to write an individual reflection report of ∼two pages about the content of the game, their personal experiences and learnings. The reflection reports were free format, although in school 1 the teacher assisted by providing four specific questions. In school 1, the reports were announced to be graded, while in schools 2 and 3 they were not graded. The approach of using individual reflection reports was chosen in order to create a free format to give every student the chance to speak up and to assure that every individual opinion would be considered. The detailed instructions can be found in the **Supplementary Table 1**. The different contexts in the three schools are summarized in **Table 4** below.

The reflection reports were analyzed using qualitative coding in order to structure and assess the students' learning outcomes and experiences. When developing the coding scheme, the following evaluation criteria of the game were used as a guidance:

- EcoCEO illustrates the concepts of linear and circular economy.
- EcoCEO explains the basic concepts and strategies of a circular economy, such as recycling, reuse, design for repair, product service systems.

- EcoCEO illustrates the impact of the scarcity of raw materials and other real-life external events on doing business.
- EcoCEO provides an impression of the role of a (sustainable) entrepreneur.
- EcoCEO is a pleasant manner to learn about the circular economy.

Analysis

The reflection reports of the students were analyzed in a qualitative manner, using the software Nvivo (Nvivo 12, 2019) in which the data were assembled, coded and analyzed. Coding has the intention to orient and represent the interplay of the related subjects around the central research topic and to structure the data to find the underlying message (Williams and Moser, 2019). Two rounds of coding were conducted. In the first round a deductive coding approach was used, i.e. the codes were based on the evaluation criteria of the game ecoCEO. The codes "linear economy" and "circular economy" were derived from the first and second evaluation criteria. The codes "link with reality" and "scarcity of raw materials" came from the third evaluation criterion and the codes "role of the entrepreneur" and "game experience" were derived from evaluation criteria five and six respectively. In the next step, the researchers coded the reflection reports accordingly. In a second round of inductive coding, the researchers analyzed the different topics discussed within each
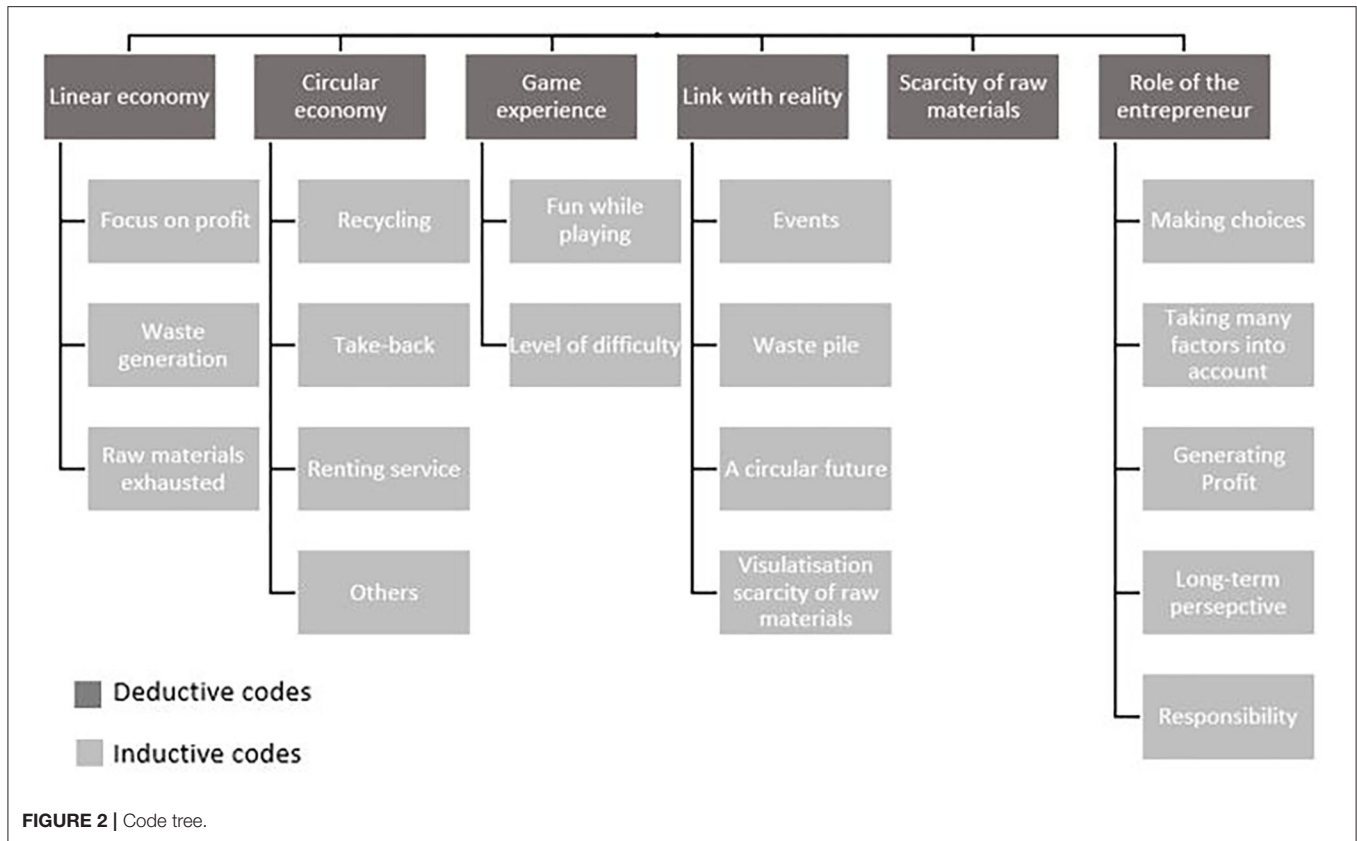
FIGURE 2 | Code tree.

specific code of the coding scheme in more depth to create sub codes. The code tree is presented below in **Figure 2**.

RESULTS

The 42 reflection reports provide a varied overview of how students perceived, interpreted and assessed the game. The following sections provide a summary description per topic (i.e., codes and subcodes), supplemented with quotes of the students to illustrate their perception. In the first column of each table the concept mentioned by the students is described. The second column indicates the number of students who mentioned something about that specific concept in their reflection report. The last column of each table contains an exemplary quote.

Linear Economy
In total 16 students wrote about the linear economy. The students wrote about the importance of making profit, waste generation and the fact that raw materials are exhausting (**Table 5**). This last element was visually presented in the game by a limited amount of playing cards.

Circular Economy
The concept of the circular economy is described by 27 students. In the game five circular solutions are provided, i.e., you can (1) recycle waste, (2) reuse components (3) take back used products from the market for repair and (4) rent out products instead of

selling them with (5) the option of repair after use. The students mentioned in their reflection reports the concepts summarized in **Table 6**.

Some other aspects of the circular economy not related to the initial codes of the coding scheme were mentioned as well. A much-discussed topic for example was the scarcity of raw materials. In most reflection reports, scarcity was described as the bridge between the linear and circular economy. In addition, some students also assumed that a circular economy is more expensive and difficult.

Role of a (Sustainable) Entrepreneur
Also, the role of entrepreneurship was discussed. Twenty students mentioned how they experienced the role of an entrepreneur during the game. They mentioned the concepts summarized in **Table 7**. When describing the process of making decisions, some students went in deeper detail about the risks and difficulties which go along with making these decisions. It is also notable that only two students mentioned that the role of CEO exceeds the task of making profit.

Link With Reality
In total 24 students mentioned in their reflection reports aspects that gave the game a realistic character (**Table 8**).

TABLE 5 | Concepts of the linear economy listed in the reflection report.

Concept	Number of students	Example quotes
Focus on profit	3	"In the linear economy […] making profit is also important."
Waste generation	4	"Within the linear economy, also a lot of waste is created […]"
Raw materials exhausted	7	"the playing cards were gone at a certain point. This illustrates in a realistic manner the linear economy: raw materials gained in bulk are exhausted."

TABLE 6 | Concepts of the circular economy listed in the reflection report.

Concept	Number of students	Example quotes
Recycling	15	"The solution of the game was that we recycled raw materials out of the waste dump or earlier produced products."
Take-back	7	"[…] be able to reuse many products instead of just throwing them away […]"
Renting service	7	"There was a renting-system so that products can be used several times."

TABLE 7 | Concepts related to the role of an entrepreneur listed in the reflection report.

Concept	Number of students	Example quotes
Making choices	15	"… different important choices have to be made in relation to investment, trading raw materials with other players and the division of labor."
Taking many factors into account	11	"Running a business is very complex, you have to consider many factors, each factor affects your business."
Generating profit	6	"You have to think about how to make as much profit as possible […]"
Not only generating profit	2	"You not only have to think about making profit. You also have to think about your employees, your machines and the debt you have to pay."
Long-term perspective	3	"How many will the investment fetch in the short and long term? It is important to think strategically and future-oriented."
Responsibility	3	"Running a company is not easy, you as an entrepreneur have a big responsibility."

TABLE 8 | Aspects listed in the reflection reports related to level of reality in the game.

Concept	Number of students	Example quotes
Events	4	"In the game the influence of the government became very clear, for example, new environmental standards were introduced, in this sense the government influenced all CEOs through the event cards."
Waste pile	2	"[…] a game that opens your eyes with how it works in the real world with the waste that is produced […]"
A circular future	9	"This [the second game phase of 'circular economy'] was the best part of the game as in the future it will be the same in the real world. Then, everyone has to be creative and think of other solutions or reallocate the trash."
Visualization scarcity of raw materials	6	"At a certain point while playing, the raw material was gone. I liked this presentation of the problem as it gives a realistic picture of the linear economy [...]"
Resemblance with real business world	20	"Some students were really competitive and that makes the choices even more important but it also makes it more similar to the real business world because the entrepreneurs there also work very competitively [...]"

Game Experience

More than half of the students mentioned in their reflection report that they had a nice, pleasant game experience. Although all of the students wrote something about the difficulty of the game. The fact that the materials and explanation videos were in English was mentioned by many of them as an important hurdle for understanding the game rules, since English was not the students' native language.

DISCUSSION

The qualitative data of the reflection reports were compared with the evaluation criteria stated in section Materials and methods.

Looking at the first evaluation criterion "ecoCEO illustrates the concepts of linear economy and circular economy," the researchers noticed that the majority of the participating students mentioned the circular in their reflection report and some

TABLE 9 | Comparison evaluation criteria and results.

Evaluation criteria	Result
EcoCEO illustrates the concepts of linear and circular economy.	The majority the students explicitly mentioned the circular economy in their reflection report and also the linear economy was often mentioned.
EcoCEO explains the basic concepts and strategies of a circular economy, such as recycling, reuse, design for repair, product service systems.	Following strategies of circular economy were discussed by the students: • recycling (15 students) • reusing old materials (13 students) • renting service (7 students) • design for repair (2 students)
EcoCEO illustrates the impact of the scarcity of raw materials and other external events on business.	Almost half of the statements discussed scarcity of raw materials. Some statements referred to externals events such as fluctuating market prices and government intervention.
EcoCEO provides an impression of the role of a (sustainable) entrepreneur.	Almost half of the students wrote about the role of an entrepreneur and some of them also mentioned the responsibilities that come along with this job.
EcoCEO is a pleasant manner to learn about the circular economy.	The majority declared they had fun playing ecoCEO. The difficulty level of the game and the explanation in English were often mentioned as the most important hurdles, although most students stated that after a while the gameplay went more smoothly.

students also described the linear economy (**Table 9**). The students described the linear economy as an economy where profit is top of mind, raw materials are rapidly exhausted and a lot of waste is generated since raw materials are not reused or recycled. In the game, the linear economy is depicted as consisting of three phases: (1) extracting raw materials, (2) producing products and (3) selling products which then pile up as waste. From the reflection reports, it can be concluded that the linear paradigm of take-make-sell-dispose was picked up well by these students. Also, as a result of the game mechanics, the students acknowledged the challenges of resource scarcity and waste generation that are caused by this linear way of working.

On the other hand, the circular economy is described by the students as an environmentally friendly economy in which waste and used products are recycled and products can be repaired for reselling or renting. This results in a slower use of raw materials, reuse of waste and less material depletion.

Apart from successfully showing the key differences between linear and circular economy, the game mechanics also caused some misconceptions or faulty generalizations by the students. Four students stated that a circular business model is more complex and less profitable than a linear model. Although profitability of circular models can be a barrier, especially in the short term due to upfront investment costs (Mentink, 2014), it should not be generalized. While it was not intended to convey this message in the game, it may be caused by the fact that the game starts off in a linear system, requiring additional investments in order to make the transition to a circular economy. This setup puts a lot of emphasis on the need for (costly) investments to move to a circular business model. Another, related, misconception was that a circular business model needs to be built by gradually transforming a prior linear economy model. While incremental improvement is often how business model innovation in existing businesses comes about (Foss and Saebi, 2017; Bocken et al., 2018), other business innovation strategies include the development or acquisition of additional circular models alongside linear models or the creation of circular start-ups "from scratch," or a combined approach (Geissdoerfer et al., 2017). The misconception that circular business innovation always requires a linear model to start from, is probably due to the gameplay consisting of two consecutive phases, starting in a linear economy and shifting into a circular economy after resources have run out. This structured approach was chosen in order to gradually increase the complexity of the game, avoiding having to introduce all investment options and game rules in the beginning. In order to avoid such misconceptions, a thoroughly prepared debriefing after the game is crucial. During a debriefing, the teacher can revisit concepts that need further clarification, discuss potential trade-offs between a linear and circular system in a more nuanced way and present real-life examples to help students get a deeper understanding of the way business models work. Also, by sharing their experiences with the class group, students are stimulated to make their learnings explicit, while also learning from the insights of others (Whalen et al., 2018).

Evaluation criterion 2 "ecoCEO explains in a clear way the basic concepts and strategies of a circular economy, such as recycling, reuse, design for repair, product service systems" is considered to be partially confirmed in the studied class groups (**Table 9**). In their reflection reports, the students named and discussed several circular economy strategies as vital components of a circular and sustainable business model. The strategies of "recycling" and "reuse" were mentioned most, while "design for repair" and "rental systems" (i.e., product service systems) were only mentioned in a few of the reflection reports. This is probably due to the fact that the latter strategies were relatively unknown to the students in the first place, and that they have long term benefits rather than short term benefits in the game, -as well as in reality-, which may have discouraged students to experiment with them or which may have prevented students to clearly capture their benefits within the timeframe of the game. On the contrary, the strategy of recycling is something many students are familiar with to some extent, and it gives direct benefits in the game.

TABLE 10 | Aspects listed in the reflection reports related to game experience.

Concept	Number of students	Example quotes
Fun while playing	25	"It was also nice to learn something in a pleasant manner involving you as an active participant because you are more motivated and can concentrate for a longer period of time"
Level of difficulty	42	"In the beginning the game went difficult as I did not understand the playing cards very well. When we played a couple of rounds it went better."

From the wordings used by the students in their reflections, it became clear that the visual elements and physical actions in the game helped to explain the circular economy strategies and their benefits. For example, the challenge of resource depletion as a main driver for circular economy was visually depicted by a depleting card deck, which is often mentioned by the students as a key eye-opener (e.g., "the playing cards were gone at a certain point"). Consequently, by investing in "recycling," players could recover used cards (i.e., raw materials) from the discarded card deck (which is labeled "waste deposit"). Similarly, by investing in "take-back" and "chip reuse" they could take cards (i.e., sold products) from the central card deck (which is labeled "market") and reuse them into new products for reselling. These game mechanics, involving the physical discarding and reclaiming of cards, aimed to make the material flows and product loops explicit and tangible.

Overall, ecoCEO succeeded in clearly explaining the concepts and strategies of circular economy to the students who participated in this study. Still, some strategies (e.g., recycling and reuse) were more successfully transferred than others (e.g., renting service and design for repair). To improve the understanding of all strategies and to enable all students to be actively engaged in the learning experience, it could be beneficial that the teacher acts as a game master giving instructional support during the game play (Wouters and Van Oostendorp, 2013). In that way, the teacher can facilitate the students' learning by encouraging students to experiment more with the circular strategies, providing support and additional explanations where needed and linking the cards' functions to real-life examples to foster recognition and understanding.

Evaluation criterion 3, "ecoCEO illustrates the impact of the scarcity of raw materials and other external events on business" is evaluated to be confirmed by the students' reflection reports (**Table 9**). The scarcity of raw materials was described as a tipping point in the game in 20 of the reflection reports. In the game, the challenge of material scarcity is made explicit visually, since the card deck (i.e., raw materials) gets depleted relatively quickly during the linear game phase. Facing a lack of resources, players experience difficulties when producing products, forcing them to look for solutions in terms of investing in circular strategies such as "recycling," "take-back" and "reuse." Although the challenge of resource scarcity is a central element in the gameplay, students are only stimulated to resolve the problem when the game forces them to. In the linear phase, mining is actually incentivized by the game mechanics. Other external events, such as supply disruptions, material quality issues and

government interventions, were introduced by event cards that turn up unexpectedly from the card deck. Ten percent of the students mentioned these events in their reflection reports. They also highlighted the potential vulnerability of companies toward market dynamics, for example, the effect of market price changes on profitability.

Evaluation criterion 4 focused on the role of the entrepreneur and the choices that come along with this role. Almost half of all reflections included insights related to entrepreneurship and running a company (**Table 9**). Often, students described being an entrepreneur as difficult, requiring the making of risky decisions and developing a long-term strategy. Most students mention that an entrepreneur's principal objective is to make a profit. Other students added that an entrepreneur needs to manage capital and has an important responsibility toward employees and the environment, for example, in reducing the amount of waste. So, although most students still appeal to what Andersson (2016) calls the adapting role of a business person, i.e., a business should make profit and adapt to changing regulation, we saw that the game also leaves room for the more transformative creating role of a business person. The latter is illustrated by the students who mentioned that businesses can also do good to the environment and take this as an important rationale for doing business. Although some students seem to be slightly intimidated by the perceived difficulties and the big responsibility associated with being an entrepreneur, the game succeeds in creating a realistic image of the multiple responsibilities of the entrepreneur. By illustrating the different aspects of managing a business, the game teaches these students the basic principles of entrepreneurship and decision making in a business environment.

Evaluation criterion 5 stated that "ecoCEO is a pleasant way to learn about the circular economy." An argument often raised for the introduction of game-based learning in education is that it increases motivation and engagement due to its hands-on and competitive nature (Chappin et al., 2017). Although we did not measure affective learning outcomes directly, this at least indirectly showcases that the central role of a (sustainable) entrepreneur within ecoCEO has the potential to stimulate an open attitude toward sustainability among students (**Table 9**). This is in line with Shephard (2008) finding regarding the key role for role models in affective learning. The majority of the students indicated that playing the game was a fun experience (**Table 10**), to be preferred over a teacher-directed class. The students that did not perceive the game as a motivator mainly mentioned the level of difficulty of the game (**Table 10**) and in particular the English explanations in the instruction videos as

their main stumbling blocks. Translating the game instructions in the students' mother tongue would probably solve many of the issues related to game explanation. Also, providing a visual instruction guide and encouraging students to use it, can help students to better understand the game. Challenges with regards to language issues and the complexity of the game mechanics could be addressed in a digital version of the ecoCEO game, which is to be developed in the future. Such digital version can facilitate gameplay by offering language selection at the start of the game, enforcing the game rules to prevent mistakes and providing guidance throughout the game session, including visualization of the game dynamics. Additionally, playing the game only in small classes, co-teach when the class is bigger or a game master in each group can give extra support (Wouters et al., 2013).

Limitations and Recommendations for Further Research

The reflection reports were free format in school 2 and 3, therefore consequently a lot of students did not mention explicitly the things they learnt when playing the game. In future research this could be resolved by using more specific questions to guide the reflection reports or doing individual interviews instead of reflection reports. During the analysis the researchers encountered the problem of short reflection reports to deduct clear learnings. Although the students were requested to write about two pages (i.e., about 700 words) 16 students wrote <200 words, 16 students wrote between 200 and 600 words and only 10 students wrote above 600 words. All of the students who wrote a reflection that met the requirements were from school 1 where the game was led by 2 teachers, the reflection report was based on specific questions and was graded afterwards. In the other schools, no specific questions nor grading were used. The hurdle of short reflections may be resolved by creating a higher motivation toward the reflection paper itself and the game ecoCEO. On one hand researchers suggest to decrease the difficulty of the game or an increase in support while playing to increase intrinsic motivation. On the other hand, a graded reflection report could increase the extrinsic motivation to put more effort in the writing, although it may also increase the risk for "socially desirable answers." Other suggestions could be to use more specific questions or to do interviews instead of reflection reports which allow the researchers to ask additional questions. This method would be more time-consuming but the researchers would like to underline the importance of individual interviews to ensure that students can give their own opinion.

Other limitations of the research are the small sample size of 42 reflection reports. Furthermore, the research study was done in three different schools, which are characterized by differences in general knowledge of students and teachers and differences in school culture. While these differences provide insights into the experiences of the game in different contexts, it makes the reports harder to compare. Also, the setup of the research was slightly different in the three schools, which probably also caused the differences in reflection reports. Based on this, some

recommendations for future research are formulated. First of all, ecoCEO should be tested with a different setup that remediates some of the observed difficulties, e.g., using explanation videos in mother tongue, more support during the game, a better prepared debriefing after the game and more clear guidelines about the writing of reflection reports. Another option is to transform the boardgame ecoCEO to a digital serious game and to design the digital game in accordance with Ke's (Ke, 2016) conceptual design framework regarding the design of learning-play integration in digital learning games. Also research related, a digital version of the game is valuable to investigate as it makes it possible to assess the effectiveness of the game via player interaction data (Alonso-Fernández et al., 2021) and to evaluate the playability (Vargas et al., 2014). Secondly, it would be interesting to compare the results of ecoCEO with other serious games on sustainability. Thirdly, to strengthen the validity of this research, ecoCEO should be tested in schools in other regions as well. This makes it possible to investigate if cultural influences have an effect on the learning outcomes and experiences. Furthermore, this is necessary to be able to generalize the findings. A digital version of the game will allow increasing the research sample size among different regions in an efficient way, as it can be made available in multiple languages via an easily accessible web application. Lastly other methodological approaches like interviews instead of reflection reports should be used to test the effectiveness of ecoCEO to investigate if the conclusions are the same.

CONCLUSION

Little academic research on educational activities related to the circular economy is done within the context of secondary education. This article investigated the learning outcomes and experiences of the serious game ecoCEO, which was developed to respond to upper secondary school teachers' need for engaging learning materials on circular economy. The game's aim is to introduce circular economy strategies to 16–18-year old students and let them experience the challenges of an entrepreneur within the context of ever-increasing material scarcity. Those presupposed learning goals were examined by studying reflection reports written by the students after playing the game.

The results show that the students perceived the circular economy as a solution to the challenges of resource scarcity and waste generation caused by the linear economy. Moreover, the visual elements and physical actions within the ecoCEO game support the understanding of circular economy strategies, though some strategies were more often transferred in the reflection reports than others. The same visual game mechanics confront students also with material scarcity, pushing them to explore the aforementioned circular strategies. Finally, the students acknowledged the risky decisions made and long-term strategies developed by entrepreneurs within a challenging real-life business environment of fluctuating market prices and government interventions. However, the game mechanics also caused some faulty generalizations

regarding the profitability and the starting point of a circular economy. The majority of the students enjoyed playing the game, with the game's difficulty level and the English language of the instruction videos as the main nuisances for enjoyment.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. The raw data are only available in Dutch.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because Approval was given by the school and their respective teachers. We did not ask any personal data. Reflection reports were analyzed anonymously. Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frsus.2021.690232/full#supplementary-material

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