Sustainable Life Cycle Game Design: Mixing Games and Reality to Transform Education

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ABSTRACT

Although educational games have much promise across domains, their use is not widespread due to a lack of dissemination. This lack, combined with the development costs, has led us to identifying a different approach to educational games to increase adoption of games in education. Based on the reflection of two cases, where each tried in its own way to deal with the challenges of current educational game design, we introduce an approach called sustainable life cycle game design, inspired by the cradle-to-cradle® model for product manufacturing without waste. This approach emphasizes mixing existing games and educational activities into the design, mixing the game development with education, and developing with the goal of mixing new games in the future.

Keywords

educational games, serious game design, mixed reality, sustainable life cycle design

INTRODUCTION

In the past decade there has been a resurging interest in the use of games for education (Harteveld 2011). Although more evidence continues to be warranted, there is a steadily growing body of knowledge that games have positive effects across a variety of learning domains and educational contexts (Boyle et al. 2015), which helps to continue to grow the area of educational games. Despite this confirmation, actual usage of games in education is not widespread. More problematic is that dissemination—or the adaptation of existing games in education—hardly occurs. It could be a matter of time that usage becomes more widespread or dissemination occurs; however, we argue in this paper that a different approach to educational games may be necessary to increase adoption of games in education. We call this approach *sustainable life cycle game design* (or SLC), which is inspired after the cradle-to-cradle® model by McDonough and Braungart (2002) on product manufacturing without producing waste.[1]

Our SLC approach is motivated by four reasons. First, we have the aforementioned issue of the lack of dissemination. In a review on the use of games in engineering education, Desphande and Huang (2011) conclude that "Adaptation of simulation games for engineering education remains a challenge" (pp. 399-400) and "is gradual and still not widespread" (p. 408). Generally, not just in engineering education, there are few games that are adopted beyond the particular context for which they have been developed, despite evidence of success. Of course, exceptions exist such as *Quest Atlantis* (Barab et al. 2005).

Second, an increasing amount of evidence is highlighting that educational games are used most effectively when they are considered as part of an *ecology* of learning (Salen 2008). With ecology we refer to the entire learning situation, both in and outside of the classroom. It involves the teachers, instructional material, and everything else that may be of influence. This is another argument that for increasing adoption, adaptation is key and should be considered in design approaches. With adaptation we refer to the integration of games into various educational contexts. Such integration involves more than stipulating that a game needs to be played. It involves appropriately embedding games into and with existing educational activities (Marzano 2010).

Third, developing games is extremely time consuming and expensive, with development times of a professional game production ranging from one to many years and costs going from $100K up to millions of dollars (Academic Consortium on Impact Games 2012). Combine these development costs with the lack of dissemination and the relatively short product life cycle that games seem to have—because student expectations will increase based on the fast changing game industry and because teachers lose interest in repeating the same course material after some time—and we have a pressing need to reconsider how to find a more sustainable way to make games in education work.

Fourth, opportunities exist in education to make it more sustainable. Such opportunities may go unnoticed because the focus is so much on the end product. We suggest that educational game development needs to be rethought as a *process* where various educational activities are integrated throughout—by brainstorming ideas, implementing (paper) prototypes, performing user testing, and analyzing data with students. Although this may slow the process down (analogous to organic farming, which takes an ecological or holistic approach to agriculture), the advantages are that no effort goes to "waste" and that connections are made across courses and disciplines that may benefit the eventual end product. Most importantly, making the educational game is already educational. Therefore, a focus shift should take place from product to process.

There are many possible solutions to address the current state of the field of educational games. We have seen the emergence of portals where various games are accumulated and instructional material is provided to implement these in the classroom (e.g., *BrainPOP*, see http://www.brainpop.com). There has also been a call to focus on assessment of student learning (Harteveld and Sutherland 2015). The ability for teachers to assess student performance would widely increase the adoption of games, as educational institutes are predominantly driven by testing and assessment. For this reason, Shaffer and Gee (2012) state that "We have been designing games for learning when we should have been designing games for testing" (p. 3). In our vision, which is the basis for the SLC approach, we should be re-

designing *existing* games and expanding our focus from considering a game in isolation to the entire educational context. We further believe that for this integral approach to come to fruition, educational games should be transformed into *mixed-reality* games. Mixed-reality games are games that "mix" the virtual and physical world. In the case of education, we conceive of mixed reality as "mixing" virtual gameplay activities with traditional educational activities, ranging from physical laboratory tests to lectures.

In this paper we describe how we formalized the SLC approach. The approach is based on an in-depth reflection of two cases where we tried to deal with the challenges of educational game design—and for each game we did this in a different way. The first case study "recycled" two existing games into a new game. The second case study highlights another take on the approach. With this project, a game is built from scratch; however, the intent is to build it such that non-technical people can easily develop other games with it. Therefore, much akin to the typical cradle-to-cradle® products, this game can be disassembled and put together for another purpose.

BACKGROUND

Before we describe the SLC approach and the two cases that led to it, we provide the relevant background on the current state of educational games, what educational game design approaches exist, and the topic of mixed reality, which is key to the approach.

The Promise and Challenge of Educational Games

The potential of educational games for transforming education has been identified and promoted in the past decade (Egenfeldt-Nielsen 2007; Gee 2003; Squire 2011), and various studies have provided evidence for this (Barab et al. 2005; Clark et al. 2011). Part of the appeal is that games provide immediate consequential feedback on actions and understanding in an authentic yet safe virtual space, are able to differentiate learning experiences in a way never before possible, and lastly, can position users as experts, allowing them to enact practices that they typically do not have access to or the ability for in the real world. Various other affordances are mentioned, including but not limited to the ability to engage and retrieve rich behavioral data.

However, there are many obstacles for educational games. In addition to the aforementioned development cost and need for student assessment, other obstacles are (in non-specific order): curriculum requirements leave no space for adoption, the logistics of accessibility to devices and integration into the curriculum, lack of maintenance and support for educators and technology, lack of knowledge and skills by educators to create educational games and integrate them into the curriculum, and the negative attitudes and existing sociocultural structures around education (Klopfer et al. 2009). Therefore, the lack of adoption is attributable to a variety of factors.

The approach presented in this paper attempts to address these obstacles by proposing a sustainable development model where curriculum development and integration are key elements of the design process and existing infrastructures are seen as opportunities rather than obstacles for game development. Transforming education requires far more than this approach alone but it does foster the necessary awareness of how to consider developing educational games with limited resources and constraints.

Existing Educational Game Design Approaches

Various educational game design approaches exist, whether formalized or practiced. In practice, due to the development costs, the use of commercial-Off-the-shelf games has been recommended, and successes have been reported (Squire 2011; Egenfeldt-Nielsen 2007). When such games provide capabilities to modify ("modding") then educators can adjust such games and integrate them in their curriculum as they wish. We would qualify this existing practice as a type of SLC approach; however, often commercial entertainment games do not provide much modification freedom and a game on a specific topic may not be available. Along the same lines, another recommendation has been for the educational game community to share content and ideas in addition to developing dedicated technologies for educational game development (Klopfer et al. 2009). This call for openness is a prerequisite for a successful SLC approach but so far there has been little progress to achieve this. An inhibiting factor may be the recommended practice to engage in commercial partnerships to develop high quality educational games (Young et al. 2012).

The formal educational game design approaches can roughly be categorized into two. The first category concerns those that emphasize motivation and engagement (e.g., Paras and Bizzocchi 2005). Work in this category often builds forth on the theory of flow or the motivational factors by Malone (1981) in addition to adapting established frameworks from psychology and the learning sciences. The second category is a result of the critique of the so-called edutainment games, which are educational games in the 80s and 90s where the educational content was poorly integrated with the gameplay (i.e., referred to as chocolate-covered broccoli). These approaches emphasize the appropriate consideration and integration of learning content and play (for an overview of frameworks, see Harteveld 2011, and for a more recent discussion, see Arnab et al. 2015). While some exceptions exist (e.g., the four-dimensional framework includes the "context" as dimension, see De Freitas et al. 2010), what the efforts for both categories have in common is that they focus on creating the game itself, not the wider ecosystem in which the games exist. This is an oversimplification of the complexity of educational game design because contextual factors are important (Khaled and Ingram 2012; Young et al. 2012). The SLC approach is more holistic and ecological and may be used in addition to these existing approaches.

The Opportunity of Mixed Reality

Since 2004, the EDUCAUSE Center for Applied Research (ECAR) collaborates with 200+ institutions to collect responses from more than 100,000 students about their technology experiences. In the 2012 ECAR study, about 70% of U.S. respondents mentioned they learn most in blended learning environments and 55% said they wished their instructors used more simulations or educational games (Johnson et al. 2013). One of the key findings was that "Blending modalities and using technology to engage learners is a winning combination" (p. 4). This mixing of real and virtual aspects is consistent with success stories in implementing game-based learning (e.g., Squire 2011) and a key aspect of the SLC approach.

Blended learning is accomplished in the SLC approach with *mixed reality*, a concept of merging real and virtual worlds to produce new environments where physical and digital objects co-exist and interact. The concept is related to a wider set of game technologies that make use of the physical world such as augmented reality, pervasive games, and alternate reality games. The flexibility and opportunities that mixed reality offers is critical
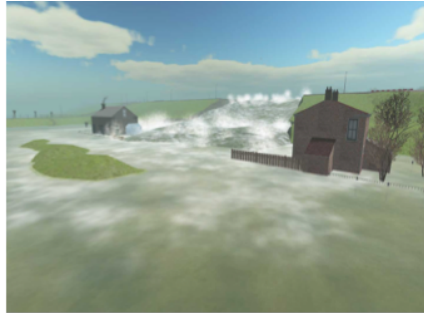
(a) *Levee Patroller*   **(b)** *CPT-Operator*

Figure 1: Games recycled into *Geo Explorer*.

for the sustainability of the SLC approach, and for the adoption of educational games in general. In fact, having student play everywhere and anywhere and using the classroom for discussing rather than play is one of the recommendations for moving educational games forward (Klopfer et al. 2009).

GEO EXPLORER CASE STUDY

The first case is the game *Geo Explorer*. It was initiated to address the gap in geotechnical engineering education, which sorely lacks field testing and practical experience. Geotechnical engineering practice depends on proper use of field and laboratory testing of undisturbed soil samples that in many cases are difficult to collect. Unfortunately, geotechnical engineering education has mainly focused on a limited number of small-sample laboratory experiments because it is geographically and cost prohibitive to conduct actual field tests. The concept behind *Geo Explorer* is to connect students with these traditional laboratory experiments by immersing them into an authentic virtual environment. In this manner, the experiential gap in geotechnical engineering is addressed and students are engaged in their education with real-world problems. The key take-away that emerged from this project for the SLC approach was to make use of existing games and mix these with other educational activities. In the following sections, we describe the two existing games that were recycled, its mixed reality design concept, and our design reflections on this project so far.

The Existing Games

To build *Geo Explorer*, the plan was to make use of two existing games: *Levee Patroller* and *CPT-Operator*. Both games have been developed by Deltares, an independent institute for applied research in the field of water and subsurface. They were built with the Unreal Engine 2 and their code has recently been released with an open source license to allow others to make modifications or mods (see http://oss.deltares.nl/web/serious-gaming/).

Levee Patroller

Levee Patroller is a single player training game (Harteveld et al. 2010). In this game, the player moves freely around a 3D environment to find all potential levee failures and appropriately deal with them using the tools of the game (e.g., handbook, map, etc.). Dealing with failures involves reporting the location and the signals that constitute the potential failures.

Next, the player must communicate the findings to a field office and assess the severity of the situation. Failures can change over time so players need to determine if the failures worsened. After diagnosing the situation, which involves determining what mechanism is causing the impending failure, players can take action and implement a stabilizing measure. If they do not implement this in time or if they use the wrong technique, a catastrophic failure and flooding results (Figure 1a). Exercises vary in failures and environment.

CPT-Operator

CPT-Operator is based on *Levee Patroller* but is a significantly different game (Figure 1b). This re-use of content and concepts exemplifies a part of the SLC approach. Originally, the game was developed for engineers to teach them how to deal with some situations that may occur during a Cone Penetration Test (CPT) operation, which is a valuable soil investigation field test for geotechnical engineers. The CPT provides detailed information on the subsoil profile and the corresponding material properties. This information is important for making design decisions for buildings and infrastructures. The game consists of three phases that together represent the complete process of a CPT: preparation, field site access, and test completion. Specifically, players start in the office where they have to retrieve information regarding their assignment, then drive the truck to the designated location. At the location, players have to prepare the site and instrument before starting the CPT, such as calibrating the sensors. The exercise ends when players decide to end the test.

The Design Concept of *Geo Explorer*

From the onset, the objective for *Geo Explorer* was to integrate virtual learning environments, such as those represented in *Levee Patroller* and *CPT-Operator*, and of "real" learning environments. This "mixing" was not pursued from a SLC perspective but from the educational perspective of embedding and integrating learning activities to achieve better learning gains and more engagement. In the context of geotechnical-engineering education, the existing real learning environments that students have access to are the physical lab tests, industry software, the classroom, and the instructional material. In connecting the separate environments, the team was inspired by the game *Sharkworld* (Harteveld et al. 2011). In this game, players have to manage the building of a shark aquarium in China. At the start, players provide their e-mail and mobile phone number. The game largely takes place in a virtual environment where players need to make managerial decisions and make use of management tools to assist in this. Both while playing and not playing in the game, players receive e-mails, text messages, and actual phone calls from characters in the game (i.e., automatic voice messages; players cannot respond back). The game's multimedia usage gives a sense of urgency and realness that a game completely played within the time and space of the virtual environment would not provide.

The design concept is that students begin assignments in the virtual environments, retrieve information about soil or levee conditions, and then use that input to run physical lab tests in the next phase, where, for example, students have to determine the grain size distribution, a coefficient of permeability, soil shear strength, and other measures that are important for the (re)design of buildings and infrastructures. The third phase concerns using industry software where students integrate both the field data and physical lab data results to make a part of the design of a building or infrastructure such as a farm silo or levee, respectively.

Finally, the virtual environments change as a result of the design recommendations. If the decisions are correct, the structures will withstand natural disasters. Otherwise, buildings will fail and flooding may be the result.

To integrate the various activities, we chose to develop a mobile phone application. The advantage of mobile phones is their flexibility, convenience, and pervasiveness (Seilhamer et al. 2013). Students carry their phones with them anywhere and are therefore the ideal platform to connect the different activities and to further engage them in a way in which *Sharkworld* was successful. In fact, others have noted how mobile technologies enable learners to interact simultaneously with both a physical (or virtual) world and (augmented) digital information, promoting in the process engagement, reflection, and new ways of aiding learning: "Mobile Technology enables immersion into a mixed reality environment and more motivating learning experience...mixed reality environments are much more apt to augment learning than purely physical or purely digital environments" (Schwabe & Göth, 2005, p. 214). One of the roles of the app is to communicate with the Non-Player Characters (NPCs) about the assignments. While in the game, players can message and receive messages from NPCs at any time. The app is also used to keep track of player performance as well as logging the input and output of the different learning environments. For example, players have to insert the physical lab test results with the app.

Design Reflections

With *Geo Explorer* the intent was to make a mixed-reality environment from the onset by recycling existing games and using a mobile app to connect the activities. Therefore, the design approach for this project had all the hallmarks of the SLC approach that we present in this paper. As we worked on the project, however, we came to realize more about what our approach is and what opportunities it brings. We also came to realize its challenges.

For example, in the beginning, we planned on integrating a simulated version of the industry software into the game, similar to *Sharkworld*. This would not be aligned with the SLC approach. Although such software often comes with Application Programming Interfaces (APIs) that allow for connecting to other software, we can get around it by identifying what output is needed. Players simply insert this output into the app that then pushes this to a database that keeps track of player progress and decisions. However, this approach comes with the trade-off of being able to track what players do while interacting with that software, which could be important for assessment purposes. This limitation on using game analytics (Seif El-Nasr et al. 2013) is in general a disadvantage of mixed-reality environments as many activities may not be able to be instrumented.

A specific challenge we came across was the limitation of certain activities. The physical laboratories need to be prepared for the students and this takes a significant amount of preparation time. This need for preparation, combined with the limited availability of these labs, required us to have the students go into the labs just once and not whenever they needed to. In practice, this means that students first have to perform all assignments in the virtual environments before continuing to the labs. This is unfortunate because students then do not go through a complete learning cycle. Therefore, by including physical learning environments, the game will continue to be challenged by the additional constraints that these environments have, as opposed to when performing everything in a virtual environment.
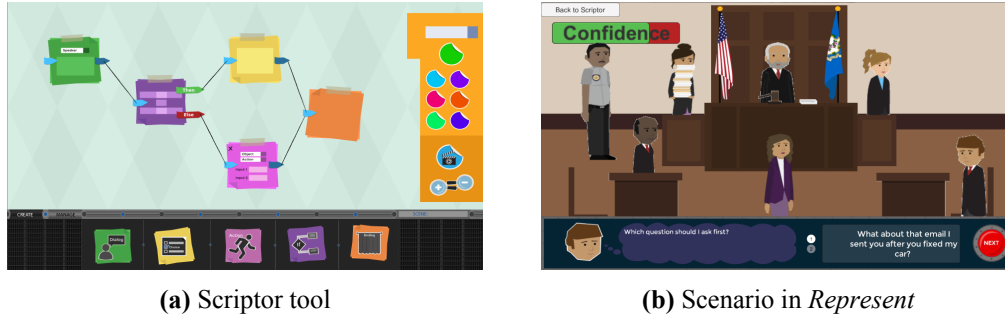
(a) Scriptor tool   **(b)** Scenario in *Represent*

Figure 2: Example of a tool and a resulting game.

Another decision was to transfer the existing games from the Unreal Engine 2 to the Unity engine and integrate them. In this new integrated environment, players can choose to a CPT or levee inspection. This makes the virtual environment more coherent and provides future opportunities to scale the project. However, this transfer proved more difficult than anticipated as many art assets were created within the Unreal Engine and unusable. In addition, a significant number of original art assets were missing, requiring the team to redo some of the work. This highlights the importance of thinking upfront about how game content may be re-used in the future—which is a way of thinking that the SLC approach supports.

MAD SCIENCE CASE STUDY

The second case is the game *Mad Science*. It is being developed to teach scientific thinking and research methods to non-scientist players. The goal is for players to create experiments that help to better understand human behavior. Players are provided the necessary authoring tools to construct settings (e.g., in the office or at the beach), characters, changes between conditions in the experiment, informed consent and debriefing forms, and the types of figures and charts they want to create (based on the collected data) to share with other players. The result of this creation process is a playable scenario where players are immersed into and need to make a decision that involves taking an action or responding to a conversation. The key take-aways that emerged from this project for the SLC approach were to mix the game development with education and think in advance of being able to mix new games in the future. In the following sections, we illustrate how the design process *Mad Science* has been mixed with education and how the derivative game *RePresent* was created. We end by describing our design reflections on this project so far.

The Design Process of *Mad Science*

As we highlighted previously, educational games are often created with limited financial resources. Often, the lack of resources to hire professional artists and programmers would be a sufficiently large obstacle that the project would end in the initial idea stage. Compared to *Geo Explorer*, we had much more limited financial resources with *Mad Science*. However, through its development we have come to realize that there exists a unique opportunity to offset this limitation by working with students throughout the design process. With limited funds for student research assistants, student projects across various courses, and independent studies, the team has been able to design a working digital prototype.

In addition to the educational opportunities for the creation of the game itself, *Mad Science*

has been used as an educational tool in a course. Using *Mad Science*, students learned key concepts from the decision sciences by playing pre-programmed scenarios testing those concepts, which also allowed the development team to validate the game as a research method (Sutherland et al. 2015). After playing the scenarios, students were presented information about the concepts and provided an opportunity to discuss them. It was found that the game could replicate the results of previous research in the literature. In this way, the attempts to test a digital prototype and validate aspects of the game were used as an educational opportunity in the classroom, rather than collecting data in a usability test and discarding the data after necessary changes were made to the game.

After playing the pre-programmed scenarios, the same students in the course were given the opportunity to create their own experiments, using paper and markers, in the same storyboard style that was to be used in the game (Harteveld et al. 2016). This scenario creation session was used to teach students about creating true experiments to test hypotheses. The prototyping session was yet another opportunity for educating students rather than simply having the design team create everything themselves. It was found that players were able to create playable scenarios and most of the student groups created true experiments.

The *Mad Science* design team used the insights gained from the course to create the scriptor tool, a tool where users make a decision tree of how a scenario unfolds (Figure 2a). Following this, students in a user-centered design course were asked to propose and conduct a usability test with the scriptor tool, and write a report about their findings and recommendations. This is another example of how we have used educational opportunities throughout the project—to the benefit of the project and the participating students.

Derivative Games

Although *Mad Science* was initially developed with only the goal of allowing players to create, run, and analyze experiments, the way in which players script their experiments lends itself well to scripting many types of scenarios. After presenting *Mad Science* to others, the design team was approached by a faculty member in the law school to see how the platform might be used to script legal scenarios. As a result, the game *RePresent* was born (Figure 2b). This game addresses the need to educate individuals who represent themselves in court—called pro se litigants—about the legal process before they have to appear in court.

Through a collaboration with a statewide legal services group, the design team scripted and modified a number of scenarios with the *Mad Science* authoring tools and combined them to create *RePresent*. In this game, players must make a series of decisions in the weeks prior to, the morning of, and during their court hearing. Although the legal representatives at first knew little about the design process or scripting scenarios using storyboards, by involving them in a number of prototyping sessions and showing how the tools in game were used, they were able to script a number of scenarios with little help from the design team. Rather than the legal services group having to create a brand new game, they were able to work with us to use and modify *Mad Science* to reduce their financial and time costs to create the game that they needed. More importantly, they were able to learn how scenarios are created so that they could create new scenarios for *RePresent* on their own in the future.

Design Reflections

Part of the intent behind *Mad Science* was determined by the experience with *Levee Patroller*. It took a significant amount of time and effort to build this 3D game (Harteveld et al. 2010); therefore, the initial intent was to build a simple 2D game where it would be easy for the project team or others to build content through the use of authoring tools instead of involving an expensive design team. Similar to *Geo Explorer*, as we worked on the project, we came to realize our design strategy and several opportunities.

An unexpected outcome was the opportunity to build entirely new games. This realization changed our design approach. In the process of creating *RePresent*, we identified a number of features in the game design that would allow future modifications to be made, with minimal effort, to create additional games out of *Mad Science*. By having several game features and mechanics that are not overly specified, the game does not have to be limited to the original game concept. This approach, if used in other games, would allow games to be modified for new uses rather than being discarded completely when it falls from favor. For example, in *Mad Science*, players can have a generic bar that tracks the amount of some variable. By leaving the bar generic, it can be easily adjusted and tied to a variable created by a new designer. In *Mad Science* the bar may reflect an in-game score on a game show, in *RePresent* the bar reflects the confidence of the player in their ability to represent themselves, in a new game it might be a health bar. The key is leaving the option as generic as possible ensuring that future designers could easily modify it for their own purposes. The flip side is that designing for this generic use slows down the current design process.

Rather than having all activities happen in the game, we changed our mind—possibly inspired by *Geo Explorer*—and saw an opportunity to make use of existing infrastructures such as websites, other software, and classrooms. In our current vision, the *Mad Science* authoring tools allow players to create the experiments and a website will be used to play and disseminate the experiments. Players can then export the data from their experiments to run analyses using their preferred statistics software. In the classroom, educators can help students with literature reviews to form and support testable hypotheses and discuss the results from the experiments. By using this mixed-reality approach, educators can create their own lesson plans and use *Mad Science* as they see fit within their context, which is the type of flexibility the SLC approach attempts to foster.

SUSTAINABLE LIFE CYCLE GAME DESIGN

When creating *Levee Patroller* and *CPT-Operator*, the design approach was specific to meet only their current needs, which is the standard approach for developing educational games. In response to this, and the realization that a different approach for the development of educational games is necessary, we tried to develop the games *Geo Explorer* and *Mad Science* in a way that addressed the challenges of current educational game design. Table 1 provides an overview of the main insights we derived from each case. Where *Geo Explorer* focused on re-using existing games and integrating it into existing curriculum activities, *Mad Science* was created with future re-use in mind and by embedding its development within educational activities. The findings from the cases show that these alternative approaches come with their own set of challenges, which means that designers will need to make trade-offs on how to approach their particular design problem.

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Game	Insight	SLC Principle	Challenge
Geo Explorer	Re-using existing games	Recycling	Re-use of assets not always feasible
	Use of mobile app to connect activities	Connecting	Activities can have inflexible constraints
	Use of existing infrastructures	Mixing	Difficult to log data and assess players
Mad Science	Envision re-use in advance	Genericity	Design for generic use delays development
	Embed development into education	Process = Product	Coordination with instructors
	Provide opportunities for adaptation	Adapting	Anticipate other uses and needs

Table 1: The main case study insights and their associated SLC principles and challenges.

Upon further reflecting on both cases, we realized that albeit they approached the problem of educational game development differently, we can derive principles from each to form the basis of a new educational game design approach. From *Geo Explorer* we can derive the principles of recycling, connecting, and mixing. Recycling involves re-using existing game code, assets and technologies; connecting involves finding ways to integrate seemingly independent and disparate educational activities; and mixing is about integrating existing infrastructures as part of the game, such as modeling or statistics software. In addition, from *Mad Science* we can derive the principles of genericity, process = product, and adapting. Genericity is about building games such that they allow for derivatives such as *RePresent*; the "process = product" emphasizes that we should refocus from aiming to develop the product to considering the game development in and of itself as an educational opportunity; and adapting is about being aware how future adopters can implement the game and providing the necessary flexibility for them to implement the game as they see fit.

These principles share close similarities with the cradle-to-cradle® (c2c) model to the design of products and systems (McDonough and Braungart 2002), which led us to formalizing this new educational game design approach based on this existing sustainable life cycle development framework. The term "cradle-to-cradle" is a play on the phrase "cradle-to-grave." It implies that the model is considerate of life and future generations by envisioning a regenerative economy where products are re-utilized and do not become waste that does not find its way back into the economy. The model makes a distinction between "biological" or "technical" nutrients. Biological nutrients are organic materials that are part of the ecological life cycle. Once used, they are decomposed and become food for others. Technical nutrients are synthetic materials that should be re-used without becoming lesser products or becoming waste. A simple example of a c2c design is a disposable cup. Once it is used, it can be disposed and decomposed in the natural environment instead of becoming waste in a landfill. Although c2c has its constraints, such as that the disassembly of products is not currently possible at recycling sites, what makes c2c attractive is that it strives for a sustainable development model, and this is what the field of educational games needs.
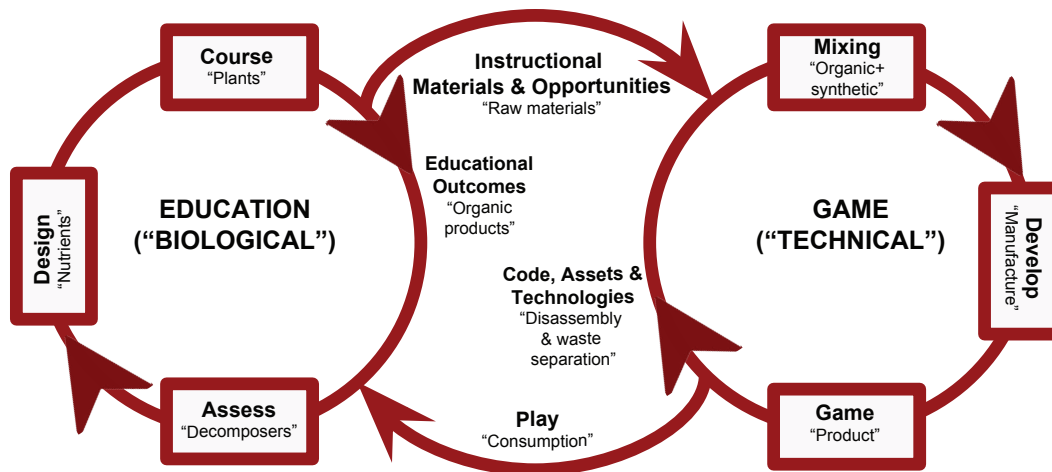
Figure 3: Sustainable Life Cycle Game Design Framework, adapted from the cradle-to-cradle® framework (original inside quotation marks).

Figure 3 shows the original c2c model and its translation to educational game design, based on the insights of our two cases. The resulting sustainable life cycle (SLC) game design framework has also two nutrients: education and game. Both have their own cycles, with education (analogous to biological nutrients) it concerns assessing course outcomes, designing the curriculum, and then teaching the course. With the game (analogous to technical nutrients), on the other hand, it concerns mixing it with other activities, developing it, and then using it. Similar to the original c2c model, the SLC approach is concerned with sustainability. It posits that games should be designed with making use of existing materials or developed with future re-use and modification in mind. Additionally, it needs to be holistic by considering the entire educational ecology with its materials and activities. To make this possible both cycles need to be meaningfully connected. Education provides materials and opportunities (the "raw materials") that can be considered to be mixed into the design and the design process, with the idea of making more interesting games, in a more cost-effective manner. The game, on the other hand, gives opportunities to improve education.

The c2c model is often summarized by the phrase "waste = food" because of its focus on re-using and anticipating re-using product elements or giving these back to the earth to be consumed by animals and insects. For sustainable educational game development it will be important to foster re-use of code, assets, and technologies but also to realize that the development itself is not waste but "food" for education.

DISCUSSION

As illustrated in Table 1, using a SLC approach to game design comes with it own set of challenges. Based on our two cases we have several recommendations to make the SLC feasible. We also discuss its limitations.

Recommendations

First, it is necessary to use art assets that can be easily repurposed or used in different game engines. If the art assets are specific to only a single engine, new designers will only be able

to use the game as a starting point if they intend to work within the same engine. Therefore, it is also necessary that any assets created by players within the game (as players are able to do in *Mad Science*) produce files that can be exported easily or that are supported across a number of game engines and platforms. Second, it is important for designers to keep code simple and use game elements that are generic when possible. This minimalist approach ensures that elements can quickly and easily be changed to meet the needs of new games. Third, by using a mixed-reality environment in the design, educators can implement elements of the game into their classroom and can use the tools they have available to create the out-of-game experience. This flexibility provides opportunities for deeper learning through multiple modes of experiential learning and for ensuring that the game can be structured to meet specific needs of different courses without needing to redesign it.

Our fourth recommendation is that game design needs to be flexible in the type of data that is produced. If the data that can be captured is specific to the constraints or needs of the current game, future designers may not be able to modify the code to log and output the necessary data to analyze or feed back into other areas of the game to create meaningful learning objectives and experiences. Finally, educators need to see not only the final game product as an educational artifact but must treat the entire design process as an educational endeavor. By having students from different fields of study involved in the process, the end product will likely be more adaptable for other areas and the students will have the opportunity to learn their own craft through hands-on educational experiences.

We argue for the SLC approach and discuss the need to make games available and generic enough to modify. If we expect that others would be able to pick up a game and modify it for their own use, others would need to be able to easily access and modify the source code. There is an inherent desire to protect our creative output but it is this protection that often means our products are not able to be reused and may never be adopted by others. This protection is necessary if the goal is commercial success. However, for education, this is almost never the goal. For the most part, designers of non-commercial educational games only hope to have their games reach learners and help them to learn. We argue that for these designers and for these games, it is necessary to make the source code available.

Limitations

Although open source is necessary for educational games, the first limitation is that designers may not want their content to be easily modified or used to make new games, especially when creating commercial games. However, we do not believe that SLC should be avoided in commercial game design because it may benefit these game companies to allow educators or other studios to reuse or modify old game titles that are not profitable anymore.

Second, using mixed-reality environments for the design of games is initially limited to the real-world resources and tools available to the designer. As we discussed with *Geo Explorer*, limited availability of specialized equipment or computer labs may require the initial development and implementation of those tools in the game. It is not always possible to expect educators to have access to the necessary technology to mimic the mixed-reality environment envisioned by the original designers. While the mixed-reality nature does allow flexibility in how the game is implemented in diverse classrooms, one benefit of having the complex tools created in the game itself is that the game can be completely implemented,

regardless of the available technology. This is an important consideration, especially for educational settings where the funding for additional outside technologies may not exist.

Third, the lack of available outside technologies, as mentioned above, highlights a major concern for SLC. This concern is simply that sometimes a game requires a level of specificity that does not easily lend itself to other domains. For example, *Levee Patroller* was originally created to address very specific topics: the identification, reporting, and diagnosing of levee failures. The tools used to address levee failures are irrelevant to many other fields or tasks. Therefore, it would be difficult to implement the SLC method. However, this does not mean that it should be completely discarded. Instead, it is important to identify areas where SLC can be applied. For example, the tools may not translate to other fields but the environment might be used to create other games. The level of detail required to create immersive virtual environments is often difficult to accomplish. By using art assets that are accepted across platforms, designers can quickly replicate a virtual environment.

Finally, we previously highlighted the need to treat the entire design process as one large educational endeavor. This approach is easily accomplished by large universities, for example, because of the access to individuals in a large number of disciplines. For smaller universities and colleges, there may not exist game design, computer programming, digital arts, or human factors programs. This problem is exponentially increased when you look at the variety of skills available in K-12 settings. For many institutions, design teams, and educators, it is simply not possible to include educational components at every level of the design process. We argue, instead, that this creates an interesting challenge and opportunity to collaborate across institutions and settings.

CONCLUSION

In this paper we presented the sustainable life cycle (SLC) game design approach based on the reflection of two game development cases. In the development of both games we tried to address some of the challenges that the field of educational games faces, and in that process we came to formalize an approach that introduces a new way of thinking about how to design for these games—by mixing existing games and educational activities into the design, mixing the game development with education, and developing with the flexibility to mix new games in the future. As this approach was the result of only two cases, which each showed a different take on the SLC approach, more ways of accomplishing the vision of "regenerative play" may be possible. Additionally, not all educational game design projects may qualify for the SLC approach. In certain cases a complete new innovation is simply necessary. Future work should consider alternative SLC strategies as well as how the approach should be disseminated to assist in transforming education.

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ENDNOTES

1. Cradle-to-cradle® is a registered trademark of McDonough Braungart Design Chemistry, LLC.

BIBLIOGRAPHY

Academic Consortium on Impact Games. 2012. "Games for impact: The transformational game development process." Washington, DC: Academic Consortium on Impact Games.

Arnab, S., T. Lim, M. B. Carvalho, F. Bellotti, S. De Freitas, S. Louchart, N. Suttie, R. Berta, and A. De Gloria. 2015. "Mapping learning and game mechanics for serious games analysis." *British Journal of Educational Technology* 46 (2): 391–411.

Barab, S., M. Thomas, T. Dodge, R. Carteaux, and H. Tuzun. 2005. "Making Learning Fun: Quest Atlantis, A Game Without Guns." *Educational Technology Research and Development* 53 (1): 86–107.

Boyle, E. A., T. Hainey, T. M. Connolly, G. Gray, J. Earp, M. Ott, T. Lim, M. Ninaus, J. Pereira, and C. Riberio. 2015. "An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games." *Computers and Education.*

Clark, D. B., B. Nelson, H. Chang, C. M. D'Angelo, K. Slack, and M. Martinez-Garza. 2011. "Exploring Newtonian mechanics in a conceptually-integrated digital game: Comparison of learning and affective outcomes for students in Taiwan and the United States." *Computers and Education* 57 (3): 2178–2195.

De Freitas, S., G. Rebolledo-Mendez, F. Liarokapis, G. Magoulas, and A. Poulovassilis. 2010. "Learning as immersive experiences: Using the four-dimensional framework for designing and evaluating immersive learning experiences in a virtual world." *British Journal of Educational Technology* 41 (1): 69–85.

Deshpande, A. A., and S. H. Huang. 2011. "Simulation games in engineering education: A state-of-the-art review." *Computer Applications in Engineering Education* 19 (3): 399–410.

Egenfeldt-Nielsen, S. 2007. *Beyond Edutainment: The Educational Potential of Computer Games.* London, UK: Continuum Press.

Gee, J. P. 2003. *What Video Games Have To Teach Us about Learning and Literacy.* New York, NY: Palgrave Macmillan.

Harteveld, C. 2011. *Triadic game design: Balancing reality, meaning and play.* London, UK: Springer.

Harteveld, C., G. Bekebrede, J. Lo, A.-J. Plomber, and B. Jordaan. 2011. "Make It Fun Or Real: Design Dilemmas And Their Consequences On The Learning Experience." In *Bonds and Bridges: Facing the Challenges of the Globalizing World with the Use of Simulation and Gaming.* Warsaw, Poland: Poltext.

Harteveld, C., R. Guimarães, I. S. Mayer, and R. Bidarra. 2010. "Balancing play, meaning and reality: The design philosophy of Levee Patroller." *Simulation & Gaming* 41 (3): 316–340.

Harteveld, C., and S. C. Sutherland. 2015. "The goal of scoring: Exploring the role of game performance." In *Proceedings of the 2015 ACM Conference on Computer-Human Interaction.* New York, NY: ACM Press.

Harteveld, C., S. C. Sutherland, G. Smith, C. Talgar, and A. J. Stahl. 2016. "Standing on the Shoulders of Citizens: Exploring Gameful Collaboration for Creating Social Experiments." In *49th Hawaii International Conference on System Sciences (HICSS)*. Kauai, Hawaii: IEEE Press.

Johnson, L., S. Adams Becker, M. Cummins, V. Estrada, A. Freeman, and H. Ludgate. 2013. *NMC Horizon Report: 2013 Higher Education Edition (2013)*. Austin, TX: New Media Consortium.

Khaled, R., and G. Ingram. 2012. "Tales from the Front Lines of a Large-scale Serious Game Project." In *Proceedings of the 2012 ACM Conference on Computer-Human Interaction,* 69–78. New York, NY, USA: ACM Press.

Klopfer, E., S. Osterweil, and K. Salen. 2009. *Moving learning games forward: Obstacles, opportunities and openness.* Cambridge, MA.

Malone, T. W. 1981. "Toward a theory of intrinsically motivating instruction." *Cognitive science* 5 (4): 333–369.

Marzano, R. J. 2010. "Using Games to Enhance Student Achievement." *Meeting Students Where They Are* 67:71–72.

McDonough, W., and M. Braungart. 2002. *Cradle to cradle: Remaking the way we make things.* New York, NY: Palgrave MacMillan.

Paras, B., and J. Bizzocchi. 2005. "Game, Motivation, and Effective Learning: An Integrated Model for Educational Game Design." In *Proceedings of the Digital Game Research Association (DiGRA) Conference.* Vancouver, CA: DiGRA.

Salen, K. 2008. *The ecology of games: Connecting youth, games, and learning.* Cambridge, MA: MIT Press.

Schwabe, G., and C. Göth. 2005. "Mobile learning with a mobile game: design and motivational effects." *Journal of computer assisted learning* 21 (3): 204–216.

Seif El-Nasr, M., A. Drachen, and A. Canossa, eds. 2013. *Game analytics: Maximizing the Value of Player Data.* London, UK: Springer.

Seilhamer, R. M., B. Chen, A. B. Sugar, Z. L. Berge, and L. Y. Muilenburg. 2013. *A framework for implementing mobile technology.* Routledge New York.

Shaffer, D. W., and J. P. Gee. 2012. *The Right Kind of GATE: Computer games and the future of assessment.* Charlotte, NC: Information Age Publishing.

Squire, K. D. 2011. *Video games and learning: Teaching and participatory culture in the digital age.* New York, NY: Teachers College Press.

Sutherland, S. C., C. Harteveld, G. Smith, J. Schwartz, and C. Talgar. 2015. "Exploring Digital Games as a Research and Educational Platform for Replicating Experiments." In *NEDSI Conference.* Boston, MA: NEDSI.

Young, M. F., S. Slota, A. B. Cutter, G. Jalette, G. Mullin, B. Lai, Z. Simeoni, M. Tran, and M. Yukhymenko. 2012. "Our princess is in another castle a review of trends in serious gaming for education." *Review of educational research* 82 (1): 61–89.