

Procedural Content Generation as an Opportunity to Foster Collaborative Mindful Learning

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ABSTRACT

The use of procedural content generation (PCG) is increasingly explored in game design. Yet so far, few have explored its use from a learning perspective. In this paper we describe how PCG provides for an opportunity for fostering collaborative mindful learning. The increase in content variety due to PCG has the potential to make players more mindful about the educational content and create incentives to discuss the content between players. We encourage scholars to investigate this interesting intersection of two research communities—PCG and educational games—and also consider other potential impact that comes from understanding how players communicate about generated content.

Categories and Subject Descriptors

I.2.1 [Artificial Intelligence] Applications and Expert Systems – Games. K.8.0 [Personal Computing] General – Games. K.3.1 [Computers and Education] Computer Uses in Education – Collaborative learning.

General Terms

Design.

Keywords

procedural content generation; mindfulness; collaborative learning; educational games; game design.

1. INTRODUCTION

Two important topics in digital game research are Procedural Content Generation (PCG) and games for learning (as highlighted by two of the workshops at this FDG conference: Workshop on Procedural Content Generation and Workshop on Games for Learning). Both topics have been around from the very beginning of the introduction of digital games as a medium and both have found an increasing amount of attention in this past decade [1]–[4]

The PCG community has been concerned largely with techniques for how to implement PCG in games, and more recently in discussing its role in game design. The community has focused primarily on technologies for content generation—graphics, level design, and/or game rules—and sometimes considered what effects it has on the player experience. We can consider this community as largely *technology-driven*. Its drive has been to see what creative accomplishments are possible within games using the

technologies that are developed by its researchers.

The games for learning community, on the other hand, has been focusing its efforts on how games could be harnessed as a tool to achieve learning outcomes. Discussions have been about why games are suitable for learning and how games need to be designed and implemented. The most prevalent issue is whether educational games are effective and how they can be made more effective. This community is *outcome-driven*; its drive has been to see what effects games have under different circumstances.

In this paper, we explore how these two communities can benefit from each other. We will make clear that the PCG community could benefit from having a new view on PCG, one that is primarily seen from a learning perspective and becomes outcome-driven in addition to technology-driven. We also posit that educational games can be made more effective with the inclusion of PCG. Its inclusion will create an opportunity for fostering *collaborative mindful learning*.

These hypotheses are elaborated by first illustrating what the missing links are in considering PCG for game design (Section 2). From there we will introduce this new view on PCG (Section 3). We conclude this paper by describing an early design concept that explores the intersection of learning and PCG (Section 4), and by encouraging others to find a synthesis between these two communities (Section 5).

2. THE ROLE OF PCG IN GAME DESIGN

With regards to game design, PCG has been broadly defined as “creating game content automatically, through algorithmic means” [3]. Recently, PCG has been applied to aspects of the game’s *design*, with research focusing on how to intelligently create levels [5]–[7], weapons [8], [9], puzzles [10], [11], and even the rules of the game itself [12], [13]. Perhaps PCG’s most common purpose in game design is to promote game replayability, by providing players with a new *experience* each time they play. One of the earliest examples of PCG used in this manner is in the game *Rogue* [14], in which the player never sees exactly the same dungeon more than once. Another experience that PCG promotes is game adaptability (e.g. [9], [15]), which focuses on changing the game dynamically based on how the game unfolds and by using procedural techniques.

There has also recently been a great deal of work looking at adaptive games; in particular, how to create game content that adapts to an *individual’s* play preferences. The *Mario AI* competition, for example, asks competitors in the level generation track to design systems that can create content that an individual player is expected to enjoy [5]. The game *Galactic Arms Race* [9] aims to create personalized weapons for players based on their past play style.

This (highly condensed) overview of PCG in game design reveals two main ways that PCG intervenes in game design: *content*

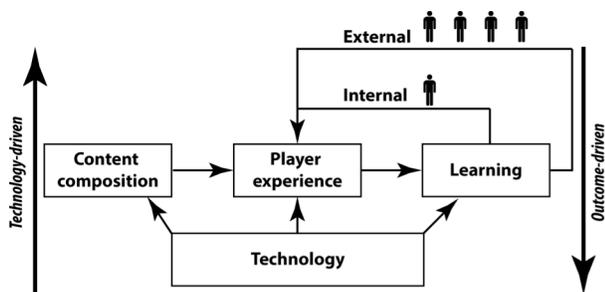


Figure 1. An overview of the relationships between the main concepts of PCG and learning.

composition, which focuses on the design of game content and the mechanics that make up the game system; and *player experience*, which studies the way *individual* players perceive the game and generated content (for more elaborate overviews, see [2], [3]). These two foci are related to each other: the composition of game content informs and constrains player experience, while the desired player experience provides context for how content should be composed [16]. Underlying these avenues are the approaches and algorithms used for content generation. Different technologies open up different design options and can make a vast difference in how a game is experienced. These aspects of PCG—technology, content composition, and player experience—have formed the core of PCG research thus far (see Fig. 1).

2.1 The Missing Links

We argue that there are two related and crucial aspects of game design that have not been considered in PCG research thus far: the impact of PCG on learning in games and the role of *multiple* players seeing and interacting with generated content. Although the connection between the serious game movement and PCG has been made, such connections have typically been considered in terms of developmental efficiencies. Creating serious games is time consuming and costly; PCG can alleviate the burden of content creation. We suggest that PCG has the ability to do far more than simply shorten development time; it has the potential to significantly increase their educational efficacy (see Section 3).

Based on this hypothesis, we propose an additional way in which PCG intervenes in game design: that of *learning*. This focus is related to the player experience focus, in that a single player’s learning experiences from seeing a variety of content will inform her overall play experience. However, it is also dependent on another aspect of PCG that has rarely been considered before: that of the community of players surrounding a game. Research into the impact and use of PCG in games has thus far been almost exclusively restricted to that of single-player experiences. What happens outside of the game—what Gee [17] has coined the *external semiotic domain*—has received little consideration. In several discussions within the PCG community, it has been mentioned that good PCG may be the kind that goes unnoticed; similar to lighting or sound design in the theater, if the player notices that content in an adaptive game changes then it may mean that the PCG system is not performing adequately. However, the use of PCG can become quite noticeable in two scenarios: on replay (as explored by those interested in promoting game replayability) and in discussions within communities of people each playing different versions of the game from each other.

As an example, consider the use of PCG in the *Civilization* series [18], [19]. In these games, the *composition* of the maps is

procedurally generated, which allows players to *experience* new (yet similar) challenges each time they play. Although there has been very little research of how players communicate about the PCG in these games, such generated content does seem to lead to a discussion about the game’s strategies on forums such as CivFanatics.com¹. From these discussions players arguably *learn* about the game’s structures and underlying system and become better at playing it. A similar phenomenon has been observed by Clara Fernandez-Vara, who noticed that players of her game *Symon* began to reverse engineer the PCG system underlying the game as part of their efforts to construct a walkthrough².

Few games have thus far used PCG for learning. Those that do engage education and training have focused on using PCG for replayability or adaptability in a single-player experience [10], [20], [21]. For example, consider the game *Refraction* that attempts to teach fractional arithmetic. The goal of using PCG in *Refraction* is to dynamically create levels that adapt to an *individual* player’s demonstrated abilities and reveal new mathematical concepts at a reasonable pace [10].

It is important to note that the impact of PCG upon learning is not only interesting for those who wish to create educational or serious games; it has been observed by many game designers that learning is an integral part of gameplay, and that good game designers teach players how to understand the systems underlying their games [22], [23]. We suggest that in order for PCG to meaningfully engage game design, it must engage in all three focus areas: content composition, player experience, and learning (see Fig. 1). In the relatively short history of the field of PCG in game design, a shift can be observed from purely technological approaches to interventions toward composition and experience. The remainder of this paper describes this third focus area of learning, and the initial stages of an experiment in this area.

3. PCG FOR LEARNING: A NEW VIEW ON PCG

We see a new view on PCG: its use for learning. We hypothesize that a PCG-driven educational game is more effective because the variety it creates stimulates *mindful and collaborative learning* and this enhances the learning outcomes that such games attempt to achieve. In this section we will elaborate on why we think that PCG stimulates these learning types.

3.1 Mindful Learning

Transfer to new situations is a critical success factor of educational game [1]. Despite this importance, no educational game researcher has considered *mindfulness theory* as put forward by Langer [24], [25]. This theory asserts that we should not be mindless about what we do, using routines and working on an automatic pilot, but rather be mindful—by being aware of our surroundings and processing new information in an elaborate and open manner. Without mindful learning, learners may end up being very rigid about what they learn, which lessens the possibility that they are able to extend what they learn to new situations. We expect that PCG-driven games foster mindfulness because the variety they create will force players to understand the

¹ For one example of such discussion, see this article on how different map generator settings impact play experience: <http://forums.civfanatics.com/showthread.php?t=484665> [Last accessed: March 4, 2013]

² Personal communication, Clara Fernandez-Vara.

underlying issues of the game. One approach may not work for another problem and this will force players to reflect why.

Mindfulness encompasses more than reflection, as it can actually be considered an *attitude* of how people deal with situations. Langer [24], [25] explains that a *mindful person* is someone who is a) able to create new categories; b) open to new information; and c) aware of more than one perspective. The incorporation of PCG in a game may affect each of these descriptions. Players will realize different “realities” of the world they encounter in the game, thus becoming critical of conceptualizations they made about the problems they have to solve in the game and also pay more attention to particular game cues.

Our position that PCG is valuable for stimulating mindful learning was inspired by a study with an educational game called *Levee Patroller* [26]. In this game players have to find and deal with failures in times or otherwise a levee will breach and the virtual land will flood. Although the study highlighted that the game is effective, the game data suggests that the game could be more effective with the use of PCG. The current game has only eight different failures and the data shows that participants learned the answers of these failures and applied these answers at a later stage of the game—sometimes even before changes to the dynamic failures were visualized. This indicates that players started to play on an automatic pilot, a danger which Langer [24], [25] and also others [27] warn about. If the failures in the game had been procedurally generated, it seems likely that players could not have behaved in this manner. They would have had to approach the failures being mindful every time because no two failures are alike.

3.2 Collaborative Learning

When multiple players communicate about a game, they are participating in the game’s external semiotic domain [17]; if players are seeing different content, we hypothesize that they will be participating in *collaborative learning*. The use of PCG in an educational game design will result in entirely different game experiences for each player. This has the following consequences:

- a) **The building of a community of players.** Learning in games happens not only within the game but also in the communities that spring up around them, such as online discussion boards or in-person game enthusiastic groups [17]. We hypothesize that players will notice and be drawn to discuss the differences between the content that they see, pointing out particularly interesting generated content.
- b) **Understanding the logic behind the game.** The exchange between members of the community surrounding the game will become more valuable compared to a game without PCG as players will be forced to communicate about a higher level strategy rather than walkthrough-style commentary. And if players understand the logic behind the game this will result in a better understanding of the material through *deeper learning* [28], [29]. Deeper learning involves a learning process through which a learner becomes capable of taking what was learned in one situation and applying it to new situations. Such learning is incredibly important, as we do not want players to only learn how to play the game [26].

3.3 Collaborative mindful learning

These two types of learning are likely to reinforce each other, which is why we speak of “collaborative mindful learning.” Seeing different game problems and discussing these will not only provide for deeper learning, it will also make players realize there is more than one perspective for any game problem, leading to

more mindfulness. The combination of mindful and collaborative learning via PCG has the potential to have a large learning effect and in this section we will explain why.

An educational game with no PCG will transfer its content exactly as how the designers envisioned this to be. This content is fixed. If PCG is added to vary the learning content, players become more mindful and are not fixated on a certain type of representation. Therefore, in a single-player game with no external domain but with PCG mindful learning will occur (Table 1).

A game with no PCG but with an external domain will provide for an opportunity for collaborative learning to occur. Players can share their experiences and discuss strategies. The resulting learning is likely stronger if PCG is used. This forces players to look beyond single solutions to game problems and understand the logic behind the game. This is the situation of collaborative mindful learning, which is a situation we think PCG will be most valuable for games with an educational purpose.

Table 1. Learning in games in terms of the combination of PCG use and considering both internal and external semiotic domains.

	Internal	External
No PCG	No mindful or collaborative learning	Collaborative learning
PCG	Mindful learning	Mindful collaborative learning

A few remarks need to be made regarding whether or not PCG is truly required for players to experience collaborative and mindful learning. First, collaborative learning is not limited to the external domain; it may occur internally in a multiplayer game as well. If the game allows for it, players can discuss, using a chat channel or other means, what the game is about. However, unless the environment is different for each player, each player will see the same content. This is typical for most multiplayer games and we hypothesize that seeing the same content would not induce mindful learning. Additionally, the amount of reflection and elaboration about the game content would likely be less in a multiplayer game because in its internal domain players will focus on playing the game rather than discussing the game. Players may discuss strategy but sooner or later they will want to jump into action.

Second, in games with emergent gameplay [30], the game without PCG can foster mindfulness as players will encounter a variety of experiences due to the mere fact that different choices by players will lead them to see the game state evolve differently. Qualitative evidence exists that such games foster discussion among players and thereby learning [4]. Except that emergent gameplay is a property that games share to a greater or lesser extent, it is also limited. The graphics and game world often remain the same. It is only the rules and the decisions made that change the game’s course. For this reason, incorporating PCG into games with emergent gameplay could still have a beneficial impact on the learning outcomes.

4. GrACE

To confirm PCG’s opportunity to foster collaborative mindful learning we initiated the development of a puzzle game called *GrACE*. It is named after Grace Hopper, a pioneering female computer scientist, and is an acronym for “Gram’s House Automatic Content Engine,” as this project is intended to investigate a PCG-driven game design of *Gram’s House*. *Gram’s*

House is the name of a larger and long term project which aims to broaden young women’s awareness of what it means to be a computer scientist and reduce the negative stereotypes surrounding the field by focusing on the collaborative nature of Computer Science (CS) and the ways in which technology can be used to help people.

This experimental game is not finished and its design as described here may likely change in the nearby future. However, it will serve as an illustration of how PCG could be used and thought of for fostering collaborative mindful learning.

4.1 Gram’s House

In a previously developed prototype for *Gram’s House*³, the player takes on the role of a young computer scientist eager to help her grandmother stay in her home. As Gram has aged, she has become less capable of performing tasks in her own home, and with nobody able to live with Gram to care for her daily, it looks like Gram will need to move to assisted living. The player chooses to use her computing knowledge to help build Gram a robot that can take the place of a human caretaker, and help Gram remain safe, happy, and self sufficient in her own home. The robot needs to be able to perform a variety of tasks to help Gram around the house, and for each task the player needs to solve a series of puzzles to help the robot. Each of these puzzles is centered on teaching a CS principle.

This prototype has two puzzles implemented: one teaches the concept of binary numbers, themed as an activation code for turning on the robot. The second puzzle teaches the concept of graph coloring by having the player assign colors to different rooms in the house. These puzzles are all *static*; all players see the same set of puzzles, and there is a limit to how many instances of the puzzle the player will see before progressing in the game. This prototype has been studied in a pilot study, with promising preliminary results: out of 35 students who played the prototype, 60% stated that they would be interested in pursuing CS further, and 66% of these students were girls. While the results from this pilot study show that girls enjoy both the theme and content of the game, we felt that the concept could be improved by introducing PCG. *GrACE* is the result of this exploration.

4.2 The game concept of *GrACE*

GrACE extends the story and context of *Gram’s House* and the first prototype focuses on teaching another CS concept, that of the minimal spanning trees. The puzzle design is inspired by the CS Unplugged activity for teaching minimal spanning trees (MSTs) [69] and has a similar focus: the player is not asked to explicitly *program* the robot to perform a task, but instead encouraged to think through algorithm design at a high level by acting out the algorithm herself and thinking through it conceptually. The game is developed for the same target group as *Gram’s House*: middle school girls (ages 11-14). Its learning objectives are as follows:

1. Players should be able to demonstrate algorithmic thinking, specifically in the context of the CS concept of minimal spanning trees.
2. Players should have a more accurate view on computer science, in terms of seeing CS as a collaborative field that can have societal impact

³ *Gram’s House* is a large-scale collaborative project, see: <http://www.gailcarmichael.com/research/projects/gramshouse> [Last Accessed: March 4, 2013]

To achieve these objectives we developed a game concept for a PCG-driven puzzle game. In this concept, the player sees a crosscut (in 2D) of Gram’s house. This house is full of memory-filled rooms, and the older style architecture means that there are many internal walls, doorways, and small sets of stairs: challenging terrain for a helper robot to navigate. In order to configure the robot to move around Gram’s house and perform tasks for her, the player is asked to lay out a conveyer belt to form a track that the robot can move along between robot installation points—these are placed in each room so that there is at least one per room. Each path between installation points has a certain cost associated with it in terms of how much conveyer belt will be needed to move between them. These costs can also be modified by properties of different doorways: rooms with heavy doors (such as doors leading to the outside), and rooms with staircases leading into them incur an additional transit cost. Players are given a limited number of conveyer belt pieces to drag into the house—each piece of conveyer belt costs money, and it is important to keep costs low. Players are asked to create the smallest possible path so that the robot can reach every room in the house. The puzzle that players are being asked to solve is equivalent to constructing a minimum spanning tree for the graph representation of the house.

The layout of the house and the number of pieces provided to the player will be procedurally generated; each player has a different “Gram” with a different house that she inhabits. It is important to note that there may be many different minimum spanning trees for any one layout; we can optionally control how many minimum spanning trees exist for a graph during the generation process. The first puzzle the player receives will be just a small portion of the house to introduce the basic concept—four connecting rooms where the weights between them are equal. The game then progressively adds more rooms to the house, asking the player to re-determine the optimal layout of conveyer belts for larger sections of the house.

4.3 Early prototype and future developments

We developed an early analog prototype of the game with rubber bands, nails, and a wooden plank and are now in the process of creating a digital version (Fig. 2). The early prototype was developed to test the concept without PCG and based on an informal test session it seemed to work. As soon as the digital version is ready we plan on iterating the game with a number of formal tests. When we have a solid prototype our intentions are to evaluate our hypotheses regarding collaborative informal learning and thereby contribute to the PCG community in highlighting the importance of PCG from a learning perspective.

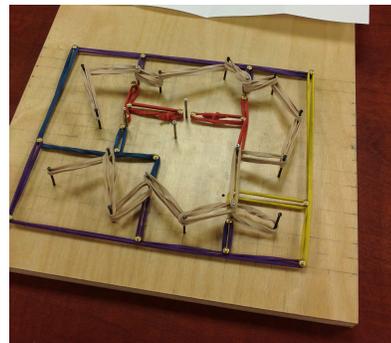


Figure 2. An early prototype of *GrACE*, created using a wooden board, nails, and rubber bands.

These developments and evaluations are still focused on the use of the game with face-to-face interactions. In the less near future we aspire to allow for online collaborations. This will probably require extending the game's concept by providing for incentives to collaborate, such as exchanging game items or making it rewarding to help one another. Players can for example decide to help others in their Gram's neighborhood who need help setting up their own helper robots. It will also require a system that enables online collaboration and we intend to build this based on the observations from the face-to-face interactions.

5. FUTURE WORK AND CONCLUSION

This paper poses that the role of PCG in games can and should be viewed from a new perspective. So far scholars have been exploring PCG for technical, design, or experience reasons. Few have considered PCG's potential for learning and those who have apply it for reasons that are similar to its use in most entertainment games: replayability and adaptability. We put forward that PCG is valuable for another reason. It provides for an opportunity for fostering collaborative mindful learning. This is because PCG allows for different game experiences both internally—a single player can see a variety of content across play experiences—and externally when communicating about the game with other players.

When these different experiences are shared and discussed among a community, players will likely better understand the educational content of a game. Because of the variety, they will learn the reasoning behind answers rather than the answers themselves. Collaborative learning is further considered to be a strong way of learning material. PCG-driven games will spark the curiosity among players and give them a reason to learn from each other.

We are currently developing a game and accompanying PCG system to further explore this relationship between PCG and learning. The game, called *Gram's House*, is intended to teach algorithmic thinking and dispel negative stereotypes surrounding computer science and is targeted at middle school girls. The PCG system we are developing for the game is named *GrACE*, and will be capable of generating a wide variety of puzzles for players to solve. We plan to study how the introduction of variety in puzzles impacts how players learn in the game and how they communicate about puzzle-solving strategy.

Although we explored primarily the advantages of incorporating PCG into an educational game in this paper, it has disadvantages. For example, incorporating procedurally generated content naturally requires designers relinquishing complete control over the final game. Many educational games thus far have been entirely scripted experiences, tightly controlled by educators who desire guarantees that all content in the game meets their educational goals. With *GrACE*, we intend to explore ways to provide educators with a sufficient amount of control over the generator, based on previous work from one of the authors [16] in building level generators that guarantee design properties. We believe it is vital that educational games be able to respond to players and provide a variety of content in order to support collaborative mindful learning. Without any emergent properties, games offer little more educational potential than a video. However, it is also important that we be able to guarantee to educators that all content seen by players is valid and appropriate.

Another possible disadvantage is that experiences may become too personalized and distinct that they become hard to compare to each other. Even if they are not that personalized and distinct, efforts on the teacher-facilitator are more arduous with PCG-driven educational games because they cannot completely predict

the outcomes of a playing session. We would also like to stress that the incorporation of PCG may not be suited for any type of educational game and especially if the learning objectives are focused on giving players the exact same message or mental model.

Although this paper does not present conclusive findings as to whether the proposed value propositions of PCG for fostering collaborative mindful learning hold true, we encourage both the PCG and educational games communities to think about the broader implications of incorporating PCG into games and assess what educational opportunities it may provide. PCG has the opportunity to drastically alter the ways in which people learn in all games. We encourage future study in this area, especially examining how PCG alters the ways in which players communicate about our games.

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