Learning Curves: Analysing Pace and Challenge in Four Successful Puzzle Games

Conor Linehan, George Bellord, Ben Kirman
University of Lincoln,
Lincoln, LN6 7TS, UK
clinehan@lincoln.ac.uk

Zachary H. Morford
University of Reno, Nevada
1664 N. Virginia Street Reno, NV
zachary.morford@gmail.com

Bryan Roche
National University of Ireland, Maynooth, Maynooth,
Co. Kildare, Ireland
bryan.t.roche@nuim.ie

ABSTRACT
The pace at which challenges are introduced in a game has long been identified as a key determinant of both the enjoyment and difficulty experienced by game players, and their ability to learn from game play. In order to understand how to best pace challenges in games, there is great value in analysing games already demonstrated as highly engaging. Play-through videos of four puzzle games (*Portal, Portal 2 Co-operative mode, Braid* and *Lemmings),* were observed and analysed using metrics derived from a behavioural psychology understanding of how people solve problems. Findings suggest that; 1) the main skills learned in each game are introduced separately, 2) through simple puzzles that require only basic performance of that skill, 3) the player has the opportunity to practice and integrate that skill with previously learned skills, and 4) puzzles increase in complexity until the next new skill is introduced. These data provide practical guidance for designers, support contemporary thinking on the design of learning structures in games, and suggest future directions for empirical research.

Author Keywords
Education; Gamification; Learning Curve

ACM Classification Keywords
K.8.0 [Personal Computing]: Games – *General;* J.4 [Computer Applications]: K.3.1 [Computers and Education]: Computer Uses in Education – *Computer-assisted instruction*.

INTRODUCTION

There has been a great deal of interest in recent years in exploring the use of games design techniques to augment and improve people's motivation for learning [31]. Good games are challenging, encourage players to spend large amounts of time on a specific task, and allow players to learn through exploration and failure [18, 27,37,39]. It is suggested that if the same type of focused, tenacious behaviour were observed of people while learning, educational outcomes would be greatly improved. Distinct sub-themes have emerged from this research domain, addressing topics such as gamified educational technology [14, 16, 28], educational games [4, 29, 30], and games to promote behavioural change [3, 6]. However, we are only beginning to see rigorous analyses of what it is about the design of video games that we should transfer to these contexts in order to best harness games design elements as motivational tools for learning.

This paper examines one specific aspect of game design that is central to both learning and enjoyment during game play; the question of how to best pace the challenges presented by games [10, 39, 2, 38]. This question has been discussed and analysed many times by games designers and academics, using a range of different perspectives. The general understanding is that challenges should be matched to a player's individual level of skill, and that challenges should increase as players skills increase. While much has been written about this concept, and some experimental studies have been undertaken [2, 30, 38], what is missing in the literature is an understanding of the design features of games that successfully achieve this effect.

Our approach to analyzing pace and challenge in this paper is based on a pragmatic approach to the understanding of problem solving taken from the behavioural psychology literature. Specifically, behavioural psychologists argue that the behavior that solves a problem is rarely a brand new insight, but is more often a combination (or chaining together) of already learned behaviors [40, 42]. In order for a games' design to support people in solving in-game challenges in this manner, it seems that a number of structural game design features must be present. For example, when learning a complex skill, players should first learn the discrete components of that skill individually, before practicing 'chaining' them together in combinations. These are precisely the structural design features examined in the games analysed in this paper. Specifically, we analyse how complexity fluctuates over the sequence of challenges presented in those games and how complexity correlates with the points at which new skills are introduced.

This is the authors version of this work. The original publication was published and should be cited as:

Conor Linehan, George Bellord, Ben Kirman, Zachary H. Morford, and Bryan Roche. 2014. Learning curves: analysing pace and challenge in four *symposium on Computer-human interaction in play* (CHI PLAY '14). ACM, New York, NY, USA, 181-190. DOI=10.1145/2658537.2658695 http://doi.acı

Since we are interested in understanding games design elements useful in the context of education, we chose to focus our analysis on commercially successful puzzle-based video games. We define puzzle-based games as those in which the fun is derived primarily from learning and applying specific skills to progress. The commercial success of the games chosen indicates that the designers of these games have successfully integrated and balanced the learning and game play elements (i.e. achieved good structures that support both learning and enjoyment). We believe that studying demonstrably engaging puzzle games can provide a wealth of information to help understand the usefulness of game design elements in wider educational contexts, where the aim is similarly on the acquisition and application of specific skills. Essentially, instead of postulating game design features that may be useful for education, or analysing participant's subjective experience of a game, we reverse engineer games that have been observed as demonstrating good design, in order to learn about their structures.

The contribution of the paper is threefold. 1) We present a novel analysis of four commercially successful puzzle games, which identifies a number of shared structural features between those games. These findings may be of immediate use to all game designers, and are particularly useful for those interested in applying game design to education. 2) Findings are coherent with previous work published by both game designers and academics regarding the pacing of challenges in games. Our paper supports and adds to that that work by providing an interesting data set that may encourage future discussion. 3) We present a simple but robust methodology for understanding, measuring and analyzing complexity in game play.

BACKGROUND

Many commentators have suggested that game design elements have the potential to improve motivation and engagement in educational contexts. However, work that specifically examines which game design elements have useful effects in which educational contexts is only beginning to emerge. In this section, we first present a brief review of literature on games and learning, focusing particularly on recent studies that examine the effects of specific game elements on measurable behaviour. We then discuss how pace and challenge have been analysed and discussed in previous game design literature. We provide a brief introduction to behavioural psychology, and the behavioural approach to understanding problem solving, as a means for providing context for our method of analysis. Finally, we justify the choice of commercially successful puzzle games as a topic worthy of study and a source of insight into the use of games in educational contexts.

Games and learning

There has been much discussion and commentary recently about how games design can be used as a tool to improve peoples motivation for learning [31,18]. Researchers and commentators demonstrate excitement at the prospect of developing educational tools and environments that maintain the motivational effects of video games, while supporting learning. Notably, while much has been written about why games should or could prove useful in improving engagement in educational contexts [18], we are only beginning to see work emerge that offers practical guidance to designers on how to recreate the motivation seen in entertainment games when designing specifically for the context of education [20, 29].

Historically, the majority of studies that have explored the effectiveness (or, more commonly, the "potential"), of games to function as educational tools, have goals other than understanding and improving the design process. Those studies rarely investigate the specific effects of specific design features on player behaviour. Rather, they typically report summative trials of specific games designed to teach specific skills or knowledge (see [5, 17, 32, 36, 45] for comprehensive reviews of empirical studies). Typically the question asked in these studies is something like "can games improve adherence to medical treatment" (i.e., [6]) or "can games teach simple mathematics" (i.e., [28]). Indeed, the term "game" is often used in a vague way that implies that games are a homogenous category, all instances of which contain common features [20]. Thus, even when the evaluation methodology is rigorous, it is difficult to learn generalisable lessons about game design from these studies.

More recently, studies have emerged that examine the effects of gamified systems on user behaviour. For example, Christy and Fox [9] examine how the use of leaderboards can evoke social comparisons and influence academic performance, sometimes negatively so. De-Marcos et al., [14] found that both gamification and social networking, when integrated with an e-learning programme, resulted in higher skill acquisition by participants. Conversely, those participants demonstrated better knowledge acquisition when using the basic e-learning programme. Koivisto & Hamari [26] examine the long-term effects of gamification on exercise behaviour, studying the service *Fitocracy*, and found that the perceived enjoyment and usefulness of gamification features decline with use, suggesting a novelty effect. Thus, while much research is being carried out, results are rarely straightforward. It is difficult to identify from studies of complete systems how discrete components of those systems effect player behaviour.

In contrast to the studies mentioned above, a small amount of recent research does analyse specific qualities of games that may be useful in the context of education. For example, Hamari [21] found that the implementation of achievement badges in a peer-to-peer trading service improved user activity, but only for those users who actively monitored their achievements. Hamari et al., [22] report a literature review of all studies that empirically examine the effects of gamification on user behaviour, finding that any positive effects of gamification were greatly dependent on context, and that gamification generally improves motivation only for those users already interested in those gamified elements. It seems that there may be differences between the types of design features necessary to draw in new users, and those necessary to maintain engagement. In summary, we are only beginning to see empirical work that provides practical direction to designers aiming to use game design as part of educational programmes and the results of those early studies are often difficult to interpret by designers.

Pace and Challenge

Game 'challenge' is one feature that is regularly discussed as important in influencing player motivation. There seems almost unanimous acceptance that games should present challenges that are matched to the players individual skill level, and that playing games is fun only if a sufficient proportion of the game challenges are mastered by the player [7, 25, 37, 39]. It is also suggested that players will not be motivated to play a game that they do not find challenging. The concept of 'appropriate challenge' is central to the idea of designing for 'flow' [12], so influential on the practice of many game designers [39].

While 'appropriate challenge' is a useful design goal, we are only beginning to see analyses of what represents an 'appropriate' level of challenge in a computer game, or how a game designer can approach the problem of ensuring that players experience it. For example, Lomas et al., [30] report two studies, featuring tens of thousands of participants, which experimentally analysed how challenge affects motivation in educational games. Both studies found that less challenging games engendered greater motivation in players than more challenging games. Alexander et al., [2] conducted an experiment with 90 participants, and found that players enjoy a game more if the difficulty provided is reflective of their gaming experience. Sampayo-Vargas et al. [38] in a study with 234 particiapnts, found that an educational game that adapted its difficulty level based on player performance produced better learning outcomes.

In this paper we suggest that the structure and pace through which challenges are introduced to players (or, the learning curve) is a feature that can be analysed objectively through examining game play. We suggest that commercially successful and well-regarded puzzle games manage this pacing in an effective manner. By analyzing the structure of these successful games we can unpick successful strategies for managing complexity and designing appropriate learning curves in games.

Behavioural Psychology

For the purposes of the current paper, we are not interested in player's subjective experience of challenge in games. Rather, we are interested in how demonstrably successful games are designed in order to present challenges to players over the course of play. Essentially, we are reverse engineering successful games that have been observed as demonstrating good design in order to learn about their structures. In order to analyse game challenge in an observational manner (i.e., through analyzing features of the game design, rather than features of player experience) we adopt an approach to understanding challenge and problem solving derived from behavioural psychology.

Behaviorism is an approach to psychology that assumes, for pragmatic reasons (see [24]), that behaviour is learned through experience. It is intentionally not concerned with hypothesised internal states such as feelings, thoughts and intentions, as those cannot currently be measured and recorded accurately in experimental conditions. The work of a behavioral psychologist therefore lies in investigating which specific features of the environment lead to particular behaviors [8]. In the current paper we are analyzing how design features of games support problem solving. Problem solving here is understood as a synonym for the actions necessary for completing puzzles in a game.

Behaviourism and Problem solving

Over the past century, many explanations have been offered to account for the apparently novel, insightful and creative behaviour exhibited by people when solving problems [33]. One explanation, offered by behavioural psychologist B.F. Skinner, seems to offer some practical guidance for the design of the structure and pacing of learning in games. Skinner [40,42] suggests that, contrary to appearances, the behavior that solves a problem is rarely a brand new insight, but is more often a novel combination of already established behaviors. For instance, a child who has been taught to pull a chain on the ceiling to flush a toilet, and also to climb on a step to reach objects, may one day climb on a step to pull a chain that is out of reach. This behaviour appears to be insightful, but it might be more simply described as the chaining together of previously learned responses (or, response chaining). Since people seem predisposed to solve problems in this way, we suggest that it would be useful for game designers to structure games to allow for this type of problem solving. This leads to one of our research questions; whether the design of highly successful games support this type of problem solving.

Notably, Gingold [19], in explaining the appeal of the game *Wario Ware* [34], describes a form of response chaining, without naming it such. Gingold proposes that the process of gradually learning simple behaviors individually and combining these as the game progresses explains the appeal of the game. Indeed, anecdotally, the structure of puzzle games, such as *World of Goo* [1] seem optimized to take advantage of the human capacity for problem solving in terms of response chaining. Game designer Dan Cook, in explaining his own practice, presents an in-depth analysis of how to structure 'skill chains' [10] over the course of game play. While not referring specifically to the behavioural psychology understanding of response chaining, he is clearly describing the same phenonmenon.

Thus, one of the goals of the current study is to examine the structure of puzzle games in order to verify whether response chaining appears important in the design of these games. Specifically, we will examine the number of individual actions necessary to complete each puzzle in each game, and whether those are new actions, or new combinations of old actions. This will allow us to chart, on a line graph [11, 41], the pace with which new information is introduced in these games. Thus, there are two basic metrics used in the analysis used in the current study:

1. The number of player actions necessary to solve an in-game problem. This represents a behavioural definition of complexity. The higher number of distinct actions necessary, the more complex the problem.

2. Whether each of those actions had been required previously in the game.

Using these two metrics we can build a picture of when new skills are introduced, how game complexity correlates with those new skills, and whether games provide space for players to practice chaining those skills with other skills before encountering the next novel skill.

Puzzle games

We define puzzle games as those video games where problem solving is the central mechanic. We suggest that studying the design of commercially successful puzzle games can teach us valuable lessons about designing game based educational technology. This is because the design goals of puzzle games are so similar to those of education. While all games must teach players the skills necessary to succeed at that game, puzzle games focus on generating fun primarily from problem solving. Hence, in order to produce successful products, designers of puzzle games must focus on ensuring that game challenges (i.e., the learning) is structured in a manner that is engaging and fun, and which ensures most players can attain the necessary skills without unreasonable frustration. These are precisely the challenges that designers must overcome in order to create useful learning experiences.

People working in game based learning rarely have the resources to do the type of rapid, iterative, player-centered development process necessary to perfect the balance and pace of a commercial game [23]. By studying the structure of puzzle games that have been hugely successful (this can be seen as a way of validating the "fun" component of these designs), we can learn some general, practical lessons about making fun games that focus on learning and applying skills. While this study does not present a massive theoretical leap forward, it helps us to generate some practical evidence-based guidance for games designers.

METHOD

Materials

It was necessary to decide upon a set of games appropriate for this study. We were interested specifically in how learning is structured in puzzle games widely experienced as fun. Thus, it was important to choose popular games. We distributed a brief online survey, to which 52 participants replied, inquiring as to the puzzle games that people found most fun, most challenging, and which made them feel most competent or intelligent. Based on participant responses, four games were chosen: *Portal* [43], *Portal 2 Co-operative mode* [44], *Braid* [35], and *Lemmings* [15].

Procedure

In order to carry out an objective analysis of the structure of those four games, we followed an observational research methodology. Specifically, "Let's Play" videos (videos where a player records and narrates gameplay experience for the benefit of spectators through online video-sharing services) were observed. The researcher took notes on game play according to a carefully defined set of metrics (see below). The raw data generated through this process is available as auxiliary material, published simultaneously with the paper. Please see that material in order to understand the process through which observations were used to generate the analysis below. In summary, each video was first watched carefully, the researcher identifying each individual skill asked of players in that game (i.e., Appendix 1, Table 2). Next, the researcher identified which of those skills were used in each individual game section (i.e., Appendix 1, Table 4). The researcher observed each of these videos a number of times in order to ensure reliability of measurement and to ensure that the optimal solution was noted. These data were used to generate an analysis of the points at which new skills were introduced (i.e, Appendix 1, Table 5) and the minimum number of actions required to complete that game section. In this way, an objective picture of puzzle complexity is built based on the puzzle design itself, rather than a subjective measure of player performance (e.g. time taken), despite the subjective nature of the play experience.

Metrics

Defining the 'puzzle' as a unit of analysis

Puzzle games typically are engaged with in a linear fashion, where simpler challenges are faced first and more complex challenges are faced after experience and skill has been gained. Thus, in order to analyse the specific way in which learning is structured and scaffolded in a puzzle game, it is useful and valid to represent specific game characteristics on a line graph. This provides a sense of how pacing is constructed in the game; how quickly the game introduces new challenges, and how it allows space for practice. It is also coherent with the methods used by behaviour analysts, both experimental [41] and applied [11]. However, in order to present data on a line graph, there must be an agreed-upon unit of analysis for the x-axis.

It was deemed inappropriate to use game 'level' demarcations provided in the narrative of the games as units of analysis in our study as 'levels' often involve a series of puzzles, particularly in the later stages of the games (see figures 1 and 2 for evidence of this in the games we analysed). Since we were interested in analysing the composition and complexity of the puzzles themselves, it was felt necessary to divide these longer levels into their constituent parts. Otherwise, longer levels would inherently seem more complex, regardless of the complexity of individual tasks they presented to players. Two categories were used to separate game sections into individual puzzles; 1) puzzles must be clearly separated geographically within the game world, either by being in different 'rooms' or by being separated by a significant distance, and 2) the actions required within each of these areas must not affect the puzzles within the other areas. In order to be considered a separate unit of analysis, both conditions must be met.

Number of actions required for the completion of a puzzle

In order to analyse how learning is structured in games, it is essential to have an objective measure of the complexity of the tasks presented throughout the game. While we recognize that there are many ways that this could be defined, in this paper, and for pragmatic reasons [24], we are interested in a simple, observable definition. We define the complexity of individual puzzles as the minimum number of actions required by the player to complete that puzzle. The higher number of distinct actions necessary, the more complex the problem.

Presentation of a novel skill

Another metric important for characterising both the complexity of an individual puzzle, as well as the overall pacing of a game, is an indication of whether or not actions required of players are novel (i.e., whether or not they have been encountered previously in the game). The point at which novel skills are introduced can be easily visualised. We also recorded each specific skill needed in to solve each puzzle in every game. However, due to space restrictions we do not report the results of this measure in full in this paper. Please refer to the auxiliary material for these data.

Using these metrics we can build a picture of when new skills are introduced, how game complexity correlates with novel skills, and whether games provide space for players to practice chaining those skills with other skills before encountering the next novel skill.

RESULTS

We discuss the results obtained from analysing each of the four puzzle games in turn. Please note that raw data is published as Appendices.

Portal

Game play in Portal is split into two main sections. Firstly the player plays through a series of 20 'test chambers' labelled from 0 to 19. Test Chambers in the game are designed to have a definite start and end point, whereas the sections after the 19th Test Chamber do not. Test chambers are also used to teach all of the skills used in the game. Considering this, the analysis will focus on those Test chambers.

Number of actions required for the completion of a puzzle

Figure 1 presents the results of our analysis of the minimum number of actions required to solve each of the puzzles in the game. Some of the test chambers were split into component puzzles, in accordance with the criteria outlined above. These are indicated with decimal numbers on the x-axis. The data within this graph shows a number of peaks and troughs in the number of skills required throughout the game. There is also a general increase in the number of actions required per test chamber something which is shown in the gradual increase in multi-section test chambers as the game progresses. This shows a distinct pattern in which the puzzles within the game get gradually more difficult before suddenly becoming much easier at distinct points within the game.

Presentation of a novel skill

Figure 1 also illustrates the points at which novel skills are introduced in the game, represented here by dots on the line graph. For Portal, this ranges from basic skills such as "moving" and "jumping" through to more advanced and specific learning such as "Re-entering a portal can further increase the player's exit momentum". Notably, there seems to be a correlation between the introduction of a novel skill, and puzzles that require a small number of player actions. The results for the 6th point at test chamber 11 however do not follow the trend. Within this chamber the player must collect the orange Portal, but is required to complete a puzzle in order to do so. Once the orange Portal is collected the player is required to complete a further four actions before the chamber is completed.

The general correlation between the troughs in the graph and the point at which the player is presented with a novel skill, suggests that upon the presentation of a novel skill the difficulty of the level is reduced. This appears to be an intentional design strategy to allow the player to understand the basics of how that skill works, before applying it in more complex contexts. The analysis shows a number of interesting ways in which the game structures learning; 1) each of the main skills are introduced separately, 2) they are typically introduced in puzzles that require few other actions, 3) from the point at which a new skill is introduced, puzzles increase in complexity up until the point at which the next new skill is introduced. It is interesting to see whether the other games follow or diverge from this pattern.

Portal 2 Co-operative Mode

In Portal 2 Co-op mode, game play is split into a number of 'courses,' each of which has a specific focus (e.g., Mass and

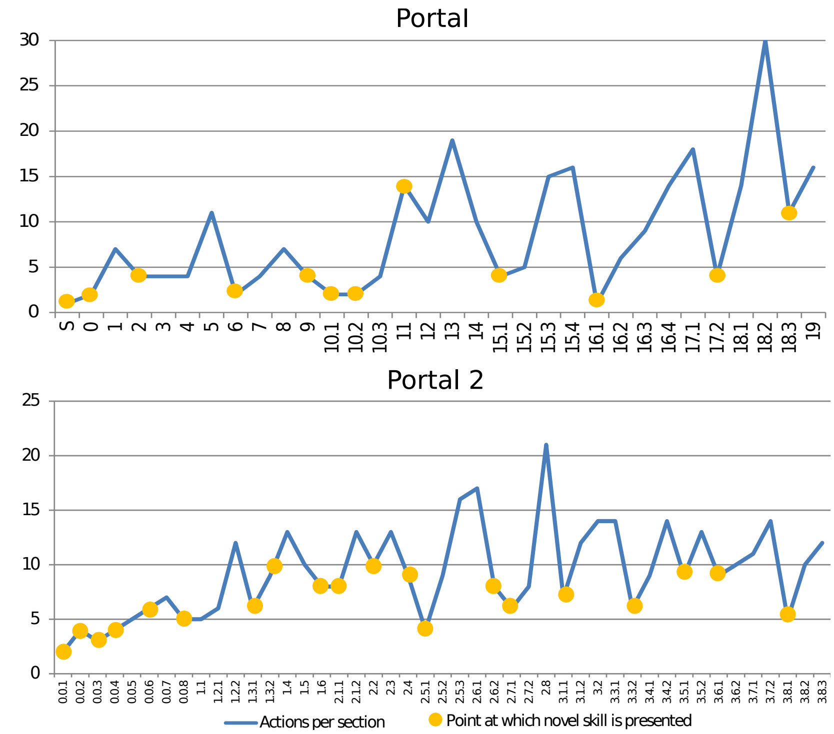

Figure 1. Minimum number of player actions required to solve successive puzzles in Portal (top panel) and Portal 2 (bottom panel).

Velocity, Hard-Light Surfaces). The sections analysed are the introduction chamber at the very beginning of the game, and the first three courses the player is required to complete. This will provide data on 23 test chambers, and 45 individual puzzles, which should be sufficient to determine how learning is structured in the game.

Number of actions required for the completion of a puzzle

Portal 2's Co-op mode includes checkpoints between puzzles, meaning the definition of puzzles as units of analysis was relatively straightforward. It should be noted that this is a two-player game, and puzzles are solved through co-operation between both players. Thus, the figure given for the *number of steps required for completion of a puzzle* is a combination of the actions made by both players. The exception to this rule are the introduction sections, where for simplicity a number of the puzzles require the two players to work separately whilst solving separate but identical puzzles. In these cases, since the puzzles are identical, we have only analysed one set of actions.

Figure 1 displays the number of actions required for the completion of the first 45 puzzles in Portal 2 Co-op mode. Results are similar to that of Portal's single player, with a number of peaks and troughs throughout the data. Across the game, puzzles show a trend of increasing numbers of actions required by the player as the game progresses.

Presentation of a novel skill
Figure 1 also illustrates the points at which novel skills are introduced in the game, represented here by dots on the line graph. Results are similar to those found with Portal 1. Specifically, most of the skills are presented at troughs in the graph, which represent puzzles that require a relatively small number of actions from players. Notably, however, during the introductory test chamber, a number of skills are taught in successive simple puzzles. This series of puzzles seems to be designed to familiarise players with the games basic controls, perhaps as a catch-up for players who have not played portal 1 or the single player mode of portal 2. Either way, it is notable that the pattern is markedly different in this section.

In summary, the three conclusions made about the structure of Portal are also true for Portal 2. This should not be a huge surprise, since the same studio produced both games. However, it is interesting to note the differences between games. Specifically, the pattern of introducing novel skills in very simple puzzles before gradually combining them with previously learned skills is even more pronounced in Portal 2 co-op mode. Indeed, the latter is explicitly divided into separate “courses,” each of which focuses on a specific set of skills.

Braid
Braid is a platform puzzle game based around a variety of time mechanics, such as reversing time, pausing time and slowing time. Braid is designed in a similar way to Portal 2’s co-op mode. The game has the player move through a series of ‘worlds’ with each one introducing the player to a variety of different mechanics the player has to use to solve the puzzles within that world. Game levels were divided into individual puzzles for analysis, based on the criteria outlined above.

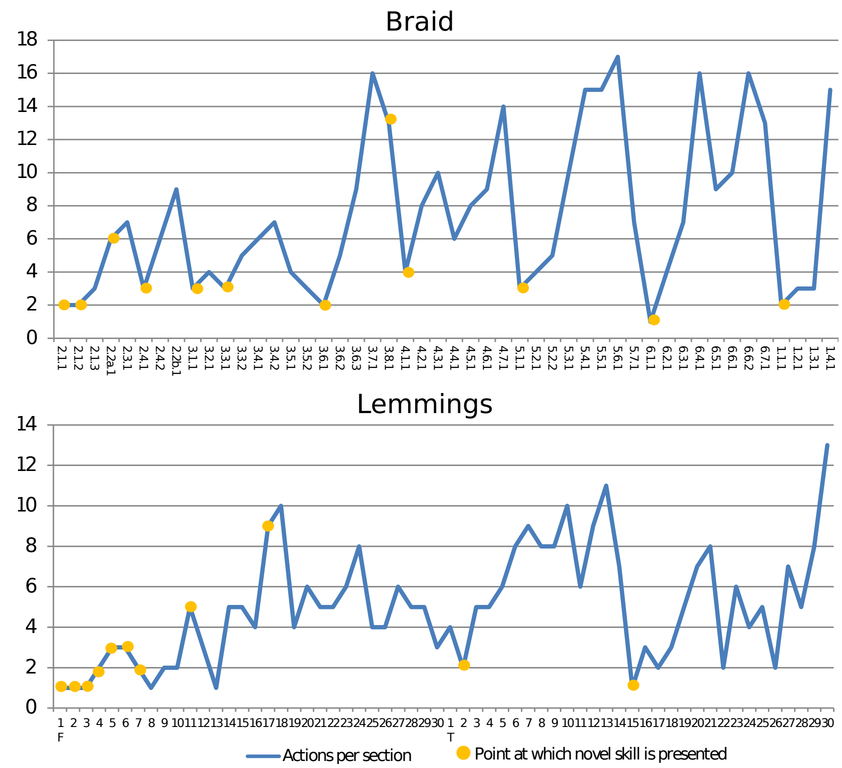

Figure 2. Minimum number of player actions required to solve successive puzzles in Braid (top panel) and Lemmings (bottom panel).

Since Braid is a platform game, many of the actions the player is required to perform involve movement around the world, such as jumping and climbing, and often a series of jumps or a series of climbs are necessary. We found that noting down each instance of movement created massive amounts of data. Thus, we simplified the analysis. Movement actions are included in our analysis as one action, as long as they are not interrupted by the performing of another type of action. So, if the player must climb, jump three times and then climb again, this is noted as three actions, not five.

Number of actions required for the completion of a puzzle
Figure 2 presents the number of actions required to complete the puzzles presented throughout Braid. Please note that in game narrative player starts at level 2 and continues through to level six before finishing on level 1. This is the reason why the numbering of the x-axis is counter-intuitive. Each of the six game worlds demonstrates a pattern where earlier puzzles in

that world require less player actions, and later puzzles require more actions. There is also a pattern where puzzles in the later game worlds generally require more actions than those presented earlier in the game.

Presentation of a novel skill

Figure 2 also illustrates the points at which novel skills are introduced in the game, represented here by dots on the line graph. Similarly with the previous games, novel skills are presented during simple puzzles that do not require many player actions. The number of actions required of the player to solve puzzles gradually increases until the next new skill is introduced.

Notably, however, there are a couple of anomalous points that don't quite fit with the rest of the data, these are at section 2.2a.1 and section 3.8.1. Section 2.2a.1 is the first point of the game in which the player is required to use a key to open a door. This happens at the very start of the level, after which the player is required to do a number of actions they have previously encountered. As there is not a significant divide between these areas, our definition of a puzzle does not allow us to divide the areas into separate puzzles. Section 3.8.1 is a similar situation, except the new skill is introduced at the end of a complex puzzle. Again, while it is quite separated from the rest of the puzzle, it cannot be defined as a separate puzzle according to our definition. However, these are only two exceptions and the pattern is quite clear throughout the rest of the game.

The analysis of Braid has shown many similarities between this game and the games within the Portal series, more specifically Portal 2's Co-op. This game has the player play through a series of different worlds, each based around a different mechanic, which the player is required to learn. Each of these worlds involves a series of puzzles which become progressively more complex as the player is exposed to more of the games mechanics.

Lemmings

This game comprises of a series of levels in which the player has to guide a group of 'Lemmings' through a series of obstacles, saving as many as possible in the process. The game has four difficulty settings, each containing 30 levels that players have to complete in sequential order. For the analysis, the first two difficulty categories will be used, consisting of a total of 60 levels. The two difficulty categories within the game are represented by the F and T on the graph, representing the fun and tricky categories respectively.

Number of actions required for the completion of a puzzle

Figure 2 presents the number of actions required to complete the puzzles presented throughout Lemmings. There is a general trend where the puzzles earlier in the game require fewer actions, while those later in the game require more actions. However, the pattern is not as obvious as in the other games. Also, like the previous games, there are quite a number of peaks and troughs as pacing of challenges is varied.

Presentation of a novel skill

Figure 2 also illustrates the points at which novel skills are introduced in the game, represented here by dots on the line graph. Interestingly, the pattern in Lemmings is very different to the previous three games. Specifically, the majority of skills that players use throughout the game are actually presented in the first seven levels of the first difficulty category, and instead of being practiced immediately, are only explored later in the game. Another difference is that some of the puzzles in which a novel skill is presented (F11 and F17) also require a very large number of actions. F11 involves the introduction of rocks that can only be dug through from one direction, while F17 introduces indestructible stone. These are obstacles that specifically require a series of player actions to overcome. Notably, when novel skills are introduced later in the game, the pattern is similar to that observed with the other three games.

The analysis of Lemmings shows that the learning curve of this game is very different to Braid and both Portal games and Braid. Lemmings introduces the player to all of the basic skills within the first 7 levels of the game. After this, the player plays through another 23 levels in which those skills are practiced in a variety of situations, before moving onto the next difficulty level. Each of these levels requires the player to use a different set of skills to overcome a different problem, but a number of the levels are ordered to encourage the player to re-use the same skills they used in the previous level, either in a different situation or with a single added skill, before moving onto a different skill.

Another interesting aspect of the game design within Lemmings is found in how some levels provide the player with an almost unlimited supply of the 8 skills within the game, and others provide the player with a small number of a specific group of skills. Within the first few levels of the game the player only has access to one or two of these skills so that the player is forced to solve the puzzle with that specific skill. This design helps the player to learn what each skill does by simplifying the skills available to them.

Of course, while it was still popular with our survey respondents, it must be noted that Lemmings is a significantly older game (i.e., 1991) than the other three games (Portal, 2007; Portal 2, 2011; Braid, 2008). Certainly, the theory and practice of designing puzzle games has advanced in the time since Lemmings was released, and as such, if it were designed today, it might follow more closely the structure seen in the other games.

DISCUSSION

The findings of this paper suggest that popular (i.e. considered fun and well-designed) puzzle games, whose core game play centres around the learning and application of skills, tend to follow a very structured way of teaching players how to use the skills available in the game. While there are some exceptions, it seems that there are some findings that are relatively consistent across all four games; 1) each of the main skills are introduced separately in the game, 2) they are introduced through a simple puzzle that requires little more than the basic performance of the new skill, 3) after the introduction of a new skill, a number of puzzles are presented in which the player is given the opportunity to practice that skill and to integrate it with previously learned skills, and 4) from the point at which a new skill is introduced, puzzles increase in complexity up until the point at which the next new skill is introduced. These findings may be of immediate use to all game designers, and are particularly useful for those interested in applying game design to education.

This paper supports design thinking emergent from the best practices of the game design community. For example, Canossa [7], Hullett [25], Schell [39], and especially Cook [10] offer guidelines for designing for complexity in games. Those authors all point to the importance of breaking complex skills into simpler components and introducing them gradually, as well as increasing complexity over the course of game play. Our findings support these suggestions on both a micro and macro level. Challenge increases both on a small scale, from the point at which a new skill is introduced, as well as on a larger scale, over the entire course of game play.

The analysis presented here, combined with previous work in the game design literature, suggests an optimal model for structuring the pace with which tasks are introduced in commercially successful games. It seems that designers should follow a pattern where the player is presented with a new skill, and then required to practice this skill along with all previously learnt skills, slowly building up the number of skills that are chained together until players are expected to use all of those in a single puzzle. While this concept is by no means a novel contribution of our paper, we have found no similar previous attempts in the literature to establish a rigorous theoretical framework for analyzing learning curves in games. In this way, this article lends empirical evidence to what is essentially a practice emergent from "popular wisdom" among game designers.

Notably, findings are also consistent with a basic behavioural psychology account of problem solving and the behavioural approach to education. Since people seem predisposed to solve problems through the type of response chaining observed in these games, future games that structure tasks chronologically so as to allow for this type of problem solving should prove successful. Indeed, applied behaviour analysis (ABA), which adopts exactly this type of approach to structuring learning, has proved incredibly successful in many different contexts in recent years [11].

Of course, the current study does not attempt to present a comprehensive analysis of learning in all puzzle games. The findings reported here are based on one study carried out with four games. These games were subjected to a rigorous, detailed analysis consisting of hundreds of hours of observation. Thus, the findings of this study are generalisable because of their depth and their ecological validity, rather than their breadth. Future work should aim to replicate these findings through application of our methodology with other popular games, in order to draw conclusions about the generalisability of the findings.

It must also be noted that, while the paper provides a clear analysis of good practice in game design, it does not suggest that the design patterns revealed here are necessarily the best way of structuring learning curves in games. Rather, these data reveal the best practice currently observed in game design. The question of whether this is indeed the optimal design strategy is an empirical question. We believe that the methods used here can inspire future work on this topic.

CONCLUSION

Four commercially successful puzzle games were analysed, using an observational methodology derived from experimental behavioural psychology research. Findings suggest that successful, fun puzzle games very carefully control the pace with which challenges are introduced chronologically (i.e., the learning curve) throughout a players interaction with the game. The findings of this study provide practical guidance for games designers, especially designers of game-based educational activities (i.e., context where instructional design is of equal importance as entertainment). They support contemporary thinking on the design of learning structures in games, and suggest future directions for empirical research.

REFERENCES

1. 2D Boy. *World of Goo.* PC. 2D Boy, 2008.
2. Alexander, Justin T., John Sear, and Andreas Oikonomou. An Investigation of the Effects of Game Difficulty on Player Enjoyment. *Entertainment Computing, 4* (2013), 53–62.

3. Baranowski, T., Buday, R., Thompson, D. I., & Baranowski, J. Playing for real: video games and stories for health-related behavior change. *Am. J. Preventive Medicine, 34* (2008), 74-82.
4. Barzilai, S., & Blau, I. Scaffolding game-based learning: Impact on learning achievements, perceived learning, and game experiences. *Computers & Education, 70* (2014), 65-79.
5. Blakely, G., Skirton, H., Cooper, S., Allum, P., & Nelmes, P. Educational gaming in the health sciences: systematic review. *J. Advanced Nursing, 65* (2009), 259-269.
6. Brown, S. J., Lieberman, D. A., Gemeny, B. A., Fan, Y. C., & Pasta, D. J. Educational video game for juvenile diabetes: results of a controlled trial. *Informatics for Health and Social Care, 22* (1997), 77-89.
7. Canossa, A. *Play-Persona: Modeling Player Behavior in Computer Games.* Copenhagen, Danish Design School Press, 2009.
8. Catania, C.A. *Learning, 4th ed.* Cornwall-on-Hudson. NY: Sloan Publishing, 1998.
9. Christy, K. R., & Fox, J. Leaderboards in a Virtual Classroom: A Test of Stereotype Threat and Social Comparison Explanations for Women's Math Performance. *Computers & Education 78* (2014), 66-77.
10. Cook, Daniel. 2007. "The Chemistry Of Game Design." *Gamasutra.* http://www.gamasutra.com/view/feature/129948/the_chemistry_of_game_design.php?print=1.
11. Cooper, J. O., Heron, T. E., & Heward, W. L. *Applied behavior analysis, 2nd ed.* NJ: Prentice Hall, 2006.
12. Csikszentmihalyi, M. *Flow: The psychology of optimal experience.* New York: Harper Perennial, 1991.
13. Deterding, S., Dixon, D., Khaled, R., & Nacke, L. From game design elements to gamefulness: defining gamification. In Proc. Mindtrek 2011, ACM Press (2011), 9-15.
14. de-Marcos, L., Domínguez, A., Saenz-de-Navarrete, J., & Pagés, C. An empirical study comparing gamification and social networking on e-learning. *Computers & Education, 75* (2014), 82-91.
15. DMA Design. *Lemmings.* Amiga. Psygnosis, 1991.
16. Domínguez, A., Saenz-de-Navarrete, J., De-Marcos, L., Fernández-Sanz, L., Pagés, C., & Martínez-Herráiz, J. J. Gamifying learning experiences: Practical implications and outcomes. *Computers & Education,* 63, (2013), 380-392.
17. Dondlinger, M.J. Educational Video Game Design: A Review of the Literature. *Journal of Applied Educational Technology, 4* (2007), 21-31.
18. Gee, J.P. *What Video Games Have to Teach Us About Learning and Literacy*. NY: Palgrave Macmillan, 2003.
19. Gingold, C. What warioware can teach us about game design. *The International Journal of Computer Game Research, 5* (2005), online article.
20. Girard, C., Ecalle, J., & Magnan, A. Serious games as new educational tools: how effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29* (2013), 207-219.
21. Hamari, J. Transforming homo economicus into homo ludens: A field experiment on gamification in a utilitarian peer-to-peer trading service. Electronic commerce Research and Applications, 12 (2013), 236-245.
22. Hamari, J., Koivisto, J., & Sarsa, H. Does Gamification Work? A Literature Review of Empirical Studies on Gamification. In System Sciences, IEEE Press, (2014) 3025-3034).
23. Harpstead, E., MacLellan, C. J., Aleven, V., & Myers, B. A. Using Extracted Features to Inform Alignment-Driven Design Ideas in an Educational Game. In *Proc. CHI 2014*, ACM Press (2014), 3329-3338.
24. Hayes, Stephen C. Why environmentally based analyses are necessary in behavior analysis. *J. Exp. Analysis of Behavior, 60* (1993), 461–463.
25. Hullet,K. *The Science of Level Design.* University of California Press, 2010.
26. Koivisto, J., & Hamari, J. Demographic differences in perceived benefits from gamification. *Computers in Human Behavior, 35* (2014), 179-188.
27. Koster, R. *A theory of fun for game design.* Scottsdale, AZ: Paraglyph Press, 2005.
28. Lee, J., Luchini, K., Michael, B., Norris, C. and Soloway, E. More than just fun and games: Assessing the value of educational video games in the classroom. In *Proc. CHI 2004*, ACM Press (2004), 1375-1378.
29. Linehan, C., Kirman, B., Lawson, S., & Chan, G. Practical, appropriate, empirically-validated guidelines for designing educational games. In *Proc. CHI 2011,* ACM Press (2011), 1979-1988.

30. Lomas, D., Patel, K., Forlizzi, J. L., & Koedinger, K. R. Optimizing challenge in an educational game using large-scale design experiments. In *Proc. CHI 2013*, ACM Press (2013), 89-98.
31. Malouf, D.B. The effect of instructional computer games on continuing student motivation. *Journal of Special Education, 21* (1987), 27-38.
32. Moreno-Ger, P., Burgos, D., Martínez-Ortiz, I., Sierra, J.L., and Fernández-Manjón, B. Educational game design for online education. *Computers in Human Behavior, 24* (2008) 2530–2540.
33. Munoz Blanco, M.I. *A naturalistic analysis of creativity in terms of the creator and the critic.* PhD dissertation, University of Reno, Nevada, 2014.
34. Nintendo R&D1. *Wario Ware.* Game Boy Advance. Nintendo, 2003.
35. Number None Inc. *Braid.* PC. Number None Inc, 2009.
36. O'Neil, H.F., Wainess, R. and Baker, E.L. Classification of learning outcomes: evidence from the computer games literature. *The Curriculum Journal, 16* (2005), 455 – 474.
37. Salen, K. and Zimmerman, E. *Rules of Play: Game Design Fundamentals.* MIT Press, Cambridge, 2004.
38. Sampayo-Vargas, S., Cope, C.J., He, Z., and Byrne, G.J. The Effectiveness of Adaptive Difficulty Adjustments of Students' Motivation and Learning in an Educational Computer Game. Computers & Education 69 (2013): 452–462.
39. Schell, J. *The Art of Game Design: A book of Lenses.* CRC Press, 2008.
40. Skinner, B. F. *Science and human behavior.* Simon and Schuster, 1953.
41. Skinner, B.F. *Cumulative Record.* New York: Appleton Century-Crofts, 1959.
42. Skinner, B. F. *About behaviorism.* Random House, 1974.
43. Valve. *Portal.* PC. Valve Corporation, 2007.
44. Valve. *Portal 2.* PC. Valve Corporation, 2011.
45. Wouters, P., & Van Oostendorp, H. A meta-analytic review of the role of instructional support in game-based learning. *Computers & Education, 60* (2013), 412-425.