# Instructional Ethology: Reverse Engineering for Serious Design of Educational Games

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## Abstract

The effective application and use of games and game technology for education requires examinations of existing artifacts, both in and out of formal educational settings, as well as the development of new theories and models for how to design games intended primarily to educate rather than entertain. One way to facilitate an understanding of how a medium like digital game technology can be used effectively in education is to study that medium's outstanding examples, regardless of their original purpose. This paper describes a methodology for analysing entertainment games that uses a synergy of reverse engineering and ethology, neither of which have been used in this context before. Normally, reverse engineering attempts to recover the original design of a software application, but in this case it will be used to generate an alternate design that can then in turn be used to inform instructional design. Ethology studies the observed behaviour of animals, but here is adapted as a method for the study of games. Through this perspective, it is possible to identify and classify built-in learning objectives and from there to associate the mechanisms and strategies employed to teach them. It is proposed that these strategies can then be used in educational games without compromising the essential qualities that have made digital games the most popular leisure activity in the western world today.

Categories and Subject Descriptors: D.2.2 [Software Engineering]: User Interfaces; D.2.7 [Distribution, Maintenance, and Enhancement] Restructuring, reverse engineering, and reengineering H5.2 [Information Interfaces and Presentation]: User Interfaces - User-centered design; Interaction styles; Theory and methods; K.3 [Computing Milieux]: Computers and Education

General Terms: Design, Experimentation, Human Factors



Additional Key Words and Phrases: Human-computer interaction, direct manipulation, reflection, education, learning, cognition, learnware

## 1. Introduction

As the interest in and the use of digital games in education continues to gather momentum, so will the demand for instructional design theories and models geared to this medium. Developing a game can be both time consuming and expensive – designing a game intended to facilitate deliberate learning requires additional consideration. Commercial games, being true to their theatrical roots, are designed primarily to entertain and although their designers may have intended lessons they wish players to take up, the game will rarely be labelled a failure if the players fail to do so. On the other hand, an entertainment game that fails to entertain ***is*** a failure. The relative ranking of these two elements, namely learning and entertainment are reversed in educational games so that an educational game that fails to help players achieve the learning objectives is a failure, while one that does not entertain may still be useable. Entertainment is related to engagement though, so the importance of entertainment can not be ignored. It seems common sense to include elements of instructional design and development when creating educational games, however, how this should be done is still not clear.

Educators have always appropriated whatever technologies are available to us for use as technologies for instruction, and digital games are no exception. This paper is a report on a methodology that has been created to examine several top-rated commercial digital games in order to identify the learning support mechanisms employed.

Some digital games made primarily for entertainment already incorporate many if not all of the major components necessary to meet the requirements of effective instruction [4, 16, 27, 28]. However, since the incorporation of formal pedagogy has not likely been a deliberate game design decision, it is unlikely that designers such as Sid Meier or Sir Peter Molyneux would have included "implement

Gagne's nine events of instruction" as part of their design specifications when creating *Civilization III* [24] or *Black and White* [25]. Because the embodiment of accepted pedagogy in existing commercial games is assumed to be largely coincidental, interviewing or otherwise studying the games designers themselves is unlikely to generate insights in a form that can be applied to instructional design directly. Consequently uncovering the mechanisms that support learning in digital games must be approached from a different angle.

## 2. Studying the Masters

If we were to take a close look at how the different forms of both classical and modern communication media (theatre, literature, film, television, etc.) have been used for educative purposes and which 'commercial' examples have been appropriated by educators, it becomes clear that the majority of the most remarkable and effective "lessons" taught to us in this way have been created by extraordinarily talented writers, playwrights, directors, and producers together with their teams (Shakespeare, Hemmingway, Twain, Spielberg, etc.). One other notion stands out. These significant creative works have, by and large, not been created by professional educators or instructional designers. What does this mean? Should we ignore what instructional design methods and theories have to say? The answer is, "Of course not". Far from trying to circumvent what educators and instructional designers have learned, we should recognize that studying these outstanding examples as "educational" objects presents us with opportunities to learn techniques and strategies we can apply to intentional learning objects, even if they weren't produced by professional educators. We should try to characterize what it is about them that makes them have the impact they do.

Looking at the practice of the 'masters' is an accepted approach to education in Fine Arts, the Performing Arts, Literature, and Music as well as a few others. All have a long tradition of learning from the masters. In Education, we study the scholars and eagerly try to assimilate their theories, and there is also a long-standing tradition of studying 'master' educators. As a medium, games are more closely aligned with film and theatre than they are with the more familiar teaching formats like textbooks, lectures or even websites. Given that, one could argue that much can be learned about how to design games by looking at the masterpieces of this profession (i.e. the best games) just as we learn about designing film by looking at film masterpieces. By "studying the masters", we can progress towards understanding the essential elements of 'good' games and begin to discuss the implications this holds for the deliberate design of educational games. There is, however, a caveat: knowing why a game is good is not the same as knowing how to make a game good. It is nonetheless an essential step in that process.

## 3. Educational Game Design

Effective application and use of games and game technology for education requires examinations of existing artifacts, both in and out of formal educational settings, as well as the development of new theories and models for how to design games intended primarily to educate rather than entertain. A growing body of literature is developing that reports on the use of commercial games in the classroom [10, 14, 17, 22, 30, 31], as well as custom-designed games [9, 33, 35], and designing games as a means to learning [21, 29]. Other reports have proposed instructional design theories and models for educational digital games [18]. Most games that have been examined in this context have either been educational games or commercial games being used in educational contexts. Also, most studies involve the use of games in formal learning situations like classrooms where the main subjects of the study are the learners. In these contexts, design research methodologies are providing useful insights [32], but there is evidence to suggest that expertise in instructional design does not necessarily prepare one to design engaging educational games [7].

One way to facilitate an understanding of how a new medium like digital game technology can be used effectively in education is to study the designs of that medium's outstanding examples, regardless of their original purpose. In other words, it is possible to uncover instructional design elements by studying the game itself and its behaviour.

However, most commercial games do not lend themselves especially well to direct analysis as educational learning objects because they were never designed as such. The methodology described in the following paragraphs is an approach to analyzing the game itself rather than the effect it has on the learners, but does so as if that game actually were an educational object. Analyzing an entertainment game as though it were an educational one when it was not designed as such necessitates a dissociation of what is learned in the game from how society values that which is learned. Doing so creates a common plane on which both educational and entertainment games can be assessed. The primary facet of the game that is

examined through this perspective is its observable behaviour.

The described method for analysis of a commercial game is based on three fundamental assumptions: 1) that players must learn and indeed do learn new things while playing the game; 2) that successful games are successful at least partially because they facilitate that learning; and 3) that it is possible to examine learning in a digital game without associating what is learned with value-laden educational aims. All three are necessary conditions that make instructional ethology an appropriate methodology in this context.

## Learning in Games

People learn throughout their lives. It's what we do. The notion that people learn during gameplay is no longer controversial. Some have even suggested that learning is really what games are all about [23]. Previous work by this author [2-4] has focused on connecting commercial video games to accepted pedagogy in a fairly general way. However, while cherry picking specific elements from a wide variety of games in order to support an argument is useful it also has its limitations. Suppose we wish to examine games in the context of Gagné's Nine Events of Instruction [15]. If we show that nine different games each implement one event well, we have still not shown that any ***one*** game is capable of embodying Gagné's theory. Further we have no evidence that ANY single game that was able to incorporate all nine events would still be a popular game. We all remember films for example that may have had one or two good moments but are otherwise unremarkable or even bad. It is a much more significant feat to look at the whole of a work and see how the various parts fit together. Fortunately, there is evidence to suggest that some games do succeed in embodying one or more complete pedagogical models [5].

## Successful Games Facilitate Learning

What makes a game successful? Critical and commercial success are both recognizable and accepted (albeit subjective) measures of a game's popularity, and popularity in turn gives some indication of that game's perceived quality as judged by players, developers, and game critics. While it is acknowledged that commercial success is not a guarantee of quality, inclusion in the top ten or twenty games in any given year is a significant achievement. There are thousands of titles released each year, and nearly 230 million games were sold in the US in 2005 [12]. That means that less than 1% (possibly less than .05%) of these games makes it onto this list. Commercial game buying decisions are based heavily on game demos and word of mouth [8] so in one way or another it is the game itself that determines its sales, and ultimately its survival. A game that offers too little or too much support is likely to be seen as too difficult or insufficiently challenging, which in turn makes it unlikely to become popular. In this way, game design is critical to game success. A part of that design unavoidably includes supporting the player while they learn what they must learn in order to progress through the game.

## Learning vs. Education

Learning happens all the time and is a natural condition of being human. Further, learning always involves some sort of change: change in what we remember, in our skills, our attitudes, or behaviours. We can learn things that are useful or useless, life-saving, or dangerous, helpful or hurtful. In short, learning has no associated implications of moral, ethical or other value: learning is not Education.

Education is value-laden. R.S. Peters, in Criteria of Education [26] states that it is impossible to consider education without implying some worthwhile and desirable change in the person being educated. Education implies learning which occurs over and above what is natural, and implies some persuasion (possibly even coercion) that is enacted on the recipient of this education. Because most commercial games were probably not designed to be educational, mining commercial games for insights into instructional game design requires a distinction between learning as a naturally occurring phenomenon, and education, which is deliberate.

Thus, learning may be a desirable outcome of education, but education is not necessary for learning to occur. Where does teaching fit in? Teaching and instruction are terms that are often used interchangeably, yet there are some that would claim they are in fact mutually exclusive [13]. The implication is that instruction is more structured, teacher-centered and directed, and more closely related to training than is teaching. Teaching includes facilitation of learning through constructivism, inquiry-based methods, and so on. Whether commercial games teach or facilitate learning is a distinction that is not germane to the current investigation.

## 4. Methodological Synergy

Uncovering the teaching or instructional mechanisms in a commercial game requires an examination of the game from the perspective of the player but not AS the player, and it requires analysis on two fronts: behavioural and structural, for both aspects play important roles in supporting learning in games. All digital games are software applications so the structural analysis draws its approach from software engineering, and specifically from a recent approach in black-box reverse engineering called ontological excavation [19]. Learning that happens while playing games is supported by the form of the application but also and perhaps more importantly, by its behaviour and that aspect of the methodology is inspired by methods used in the study of animal behaviour. The result is a new approach to analysis, called instructional ethology.

### Black Box Reverse Engineering

Instructional ethology uses a variation on black box reverse engineering as used in software engineering, but it is an approach that has not been used in this context before. Reverse engineering is the process of analysing a software program or application in order to discover how it works, and is referred to as 'black-box' if the process does not examine the original source code of the application. Normally, reverse engineering is performed in order to recover the original design of a software application for the purposes of renovation or augmentation [6], but in this case it is used to generate an alternate, hypothetical design that can then in turn be used to inform instructional design of serious games. This alternate design is one that may not have been explicitly formulated by the original designers. It focuses on the instructional aspects of the program's behaviour as observed through its interface – hence the term 'ethology'.

### Ontological Excavation

The described methodology is also loosely based on a technique called 'ontological excavation', developed by Idris Hsi [20]. This is a technique for reverse engineering that uses the morphology, or external interface of an application to uncover the ontology[1] of an application, or the application's "theory of the world". In other words, the message in the medium includes that a design is not neutral and reflects a theoretical construct held or imposed by the designers (either intentionally or not). For example, a calendar application would embody a theory about how users schedule their time. There are five main steps to this process [19]:

1. Model the user interface in a morphological map of the application's interactors, displays, and containers.
2. Generate a list of morphological elements.
3. For each element, identify the concepts (entity types and attributes) that it invokes.
4. Through dynamic interaction with the application, identify the relationships between the concepts.
5. Model the concepts and relationships into a semantic network representing the application's ontology.

Since the object of this analysis is to yield instructional elements of the application rather than its ontology the process has been adapted.

Applying this notion to a game then, a comparable theory would have to do with how players take up the game and would include how they learn what they need to learn in order to win the game. Also in the case of a game, because there is no access to the game's source code this ontology must be inferred solely from its morphology. This is accomplished by examining the game as it is being played which differs significantly from other studies of learning in games in that this analysis focuses on the game and not the player. While there are numerous sophisticated utilities and meta-languages for the description of ontological computer data models, most are designed to support code development from an object-oriented perspective, whereas instructional ethology examines the learning elements of the application which do not necessarily bear any relationship to the structure of the underlying code.

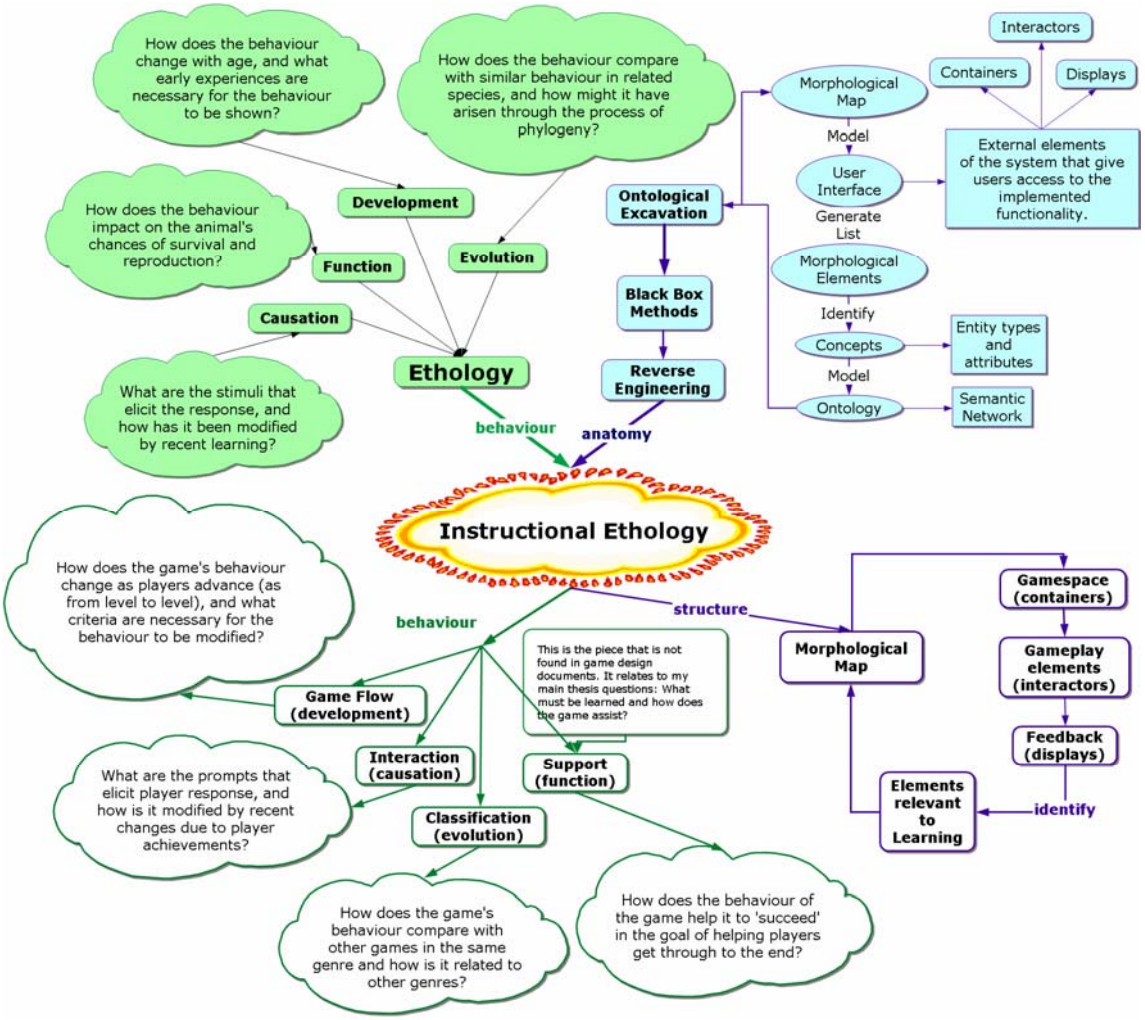
### Ethology

Ethology is the study of animal behaviour from four perspectives: anatomy, physiology, neurobiology and phylogenic history. Each has an analogy that can be applied to a digital game: anatomy corresponds to the game's structure (which is addressed through ontological excavation adaptations); physiology corresponds to its function; neurobiology maps onto the interaction; and the phylogenic history which normally addresses the evolutionary relatedness of an animal to others and corresponds to the game's similarity to other games,

[1] In computer science, an ***ontology*** is a data model that represents a set of concepts within a domain and the relationships between those concepts. The 'domain' or ***universe of discourse***, indicates the relevant set of entities that are being dealt with by quantifiers.

which in turn speaks to notions of genre. In 1963, biologist Nikolaas Tinbergen published a seminal paper [34] outlining four fundamental questions of animal behaviour which have become the cornerstones of animal behaviour research: causation, function (survival value), development (ontogeny) and evolution.

These four fundamental questions form the basis for the study of instructional ethology. The first addresses causation: what are the stimuli that elicit the response, and how has it been modified by recent learning? For a game the question is one of interaction: what are the prompts that elicit player response, and how is it modified by recent changes due to player achievements? The second deals with function: how does the behaviour impact on the animal's chances of survival and reproduction? In game terms this element is the heart of how games 'teach' and corresponds to learning support: how does the behaviour of the game help it to 'succeed' in the goal of helping players get through to the end? It is the only one of the four not likely to be described in a gamed design document. The third question asks about development: how does the behaviour change with age, and what early experiences are necessary for the behaviour to be shown? A game's behaviour develops as well but we usually call it game flow, so the question can be adapted to ask how does the game's behaviour change as players advance (as from level to level), and what criteria are necessary for that behaviour to be modified? Finally, the fourth question which speaks to evolutionary history asks, how does the behaviour compare with similar behaviour in related species, and how might it have arisen through the process of phylogeny? Obviously, games are not bound by any kind of genetic relationships, or by true evolution, but they are still categorized by genre, which of course has its roots in taxonomy. While novel approaches to known genres are possible as well as combinations of several genres embodied in a single game, the metaphor is still useful as most games can be classified by their primary form, such as a shooter, or a puzzle game. Thus the final question for instructional ethology is one of classification: how does the game's behaviour compare with other games in the same genre and how



is it related to other genres?

These guiding questions form the basis of the behavioural analysis which is the framework through which the interactive parts of the game are analyzed, and the structural analysis roughly follows the process described for ontological excavation.

## 5. Analysis

As an example of this methodology in action let's use *Katamari Damacy* [1], a well-known, critically acclaimed game with a relatively simple goal, which is to roll up objects into a large 'ball', called a katamari. The main premise for this game is that the King of All Cosmos has accidentally destroyed the stars in the sky so he charges his son, the Prince with replacing them. This is to be accomplished by going to Earth with a sticky ball called a katamari and rolling it over various objects. As the Earth is deemed to have a great many items, the Prince is to roll up as many as he can in a given time period and the King will launch the resultant ball into the sky to create a new star. There are also constellations to be made which include a additional challenge of rolling up specific kinds or objects, such as bears to create Ursa Major.

### Morphology

The structure of the game includes the two main characters: the King of All Cosmos, and his son, the Prince. The player is the Prince. The game space is divided in to two main parts: the Cosmos which contains the game options as well as access to the various play levels, and the levels which all exist on Earth.

The entities in this game that provide instructional support include the game space, which has significant conceptual coherence. All game options and play levels are accessible from the Prince's home planet[2], and each location on this planet serves a distinct function. Conceptual coherence of the visible elements is important to the usability of any software application, and games are no exception. Instructionally, conceptual coherence plays an important role in situated learning and provides the context for what is to be learned. Thus the aspects of this game's structural design that support learning are instructionally sound.

[2] There is also a 'Space Mushroom' which contains elements necessary for the multi-player mode.

Assessment is essential for learning as it provides the feedback necessary to allow learners to track their progress and in the structural analysis portion of the model this aspect is addressed through the game's displays. In *Katamari Damacy*, display or feedback elements are similarly well integrated into the game space, for example 'scores' for completed levels are represented as stars in the Cosmos, but the player may repeat a level at any time. Each accessible level is represented as an object on the Prince's home planet, and when a level is repeated, players are given the option of replacing the existing star or using the katamari to create stardust. During a course (rolling a katamari) the display shows the time remaining as well as a pictorial clock dial, the current diameter of the katamari as well as the target size (again, both numerically and pictorially), and each time an object is rolled, it is identified and its size is displayed. There are also warnings about potential hazards. Here again the game provides both guidance and feedback that is consistent and concise.

The play levels themselves are all on Earth, and each is a surrealistic but recognizable representation of some physical space, such as a house or town. The level of detail visible is directly connected to the size of the katamari. The overall structure is relatively minimalist in the sense that virtually all items are directly relevant to the game – there are few distractions and all items appear to be useable in the game.

### Ethology

This game begins with the back-story, as do many games, which sets the premise for the gameplay that follows. It also provides the support for segues between levels. The basic controls for each level involve only the left and right analog sticks, which are used to roll the katamari. At the start of the game players are led through a tutorial mode, where each distinct move sequence must be demonstrated before the player is allowed to progress. Although the game cannot ensure that players remember the moves, it can make sure that players have practiced each one. Constantly updated feedback in the game is a behaviour that helps the player track the effectiveness of various strategies and thus helping the player succeed.

The game's behaviour changes both as the player progresses through the levels and as the player progresses through each level. The point of view changes from very small to very large, which is connected to the size of the katamari. Small items are no longer visible when the katamari is large, and

objects that acted as obstacles initially become candidates for rolling. As is typical in level progression, the requirements increase as the levels do and both the target size of the katamari increases as well as a decrease in the relative amount of time allotted to complete the task.

While the cultural perspective of the game's design clearly affects the 'personality' of the King, functionally it does not impact on the game's behaviour. The King offers little verbal encouragement, even when levels are completed well within the limits and provides ample criticism when levels are missed. However, levels can be attempted as often as desired with no consequences for failure – failure to complete a level does not adversely affect other parts of the game. The comments by the king offer little in the way of positive reinforcement, but as they do not affect the function of the game, they can be ignored. Thus, from an instructional ethology perspective, the king's comments are irrelevant.

Classification of this game is more of a challenge than most, and the identified genre of this game is often listed as novelty, or miscellaneous. In terms of behaviour, it could be classified as a puzzle game, and as such compares to other classics like *Tetris* [11]. When examined in this light, it can be seen that both structurally and behaviourally, puzzle games like *Katamari Damacy*, *Tetris*, *Brain Age* and others have much in common.

## 6. Conclusion

*Katamari Damacy* is an example of a highly successful game that facilitates learning what players need to succeed in the game through many dimensions. Even though any claims to educational content in this game would be a stretch, the overall structure and behaviour could be used as models for games that are educational – for example, items could include physical characteristics besides size that would affect how they were rolled. Lessons learned from this analysis that are more broadly applicable would include the importance of conceptual coherence, direct relationships between player action and game behaviour, and constant, straightforward, and relevant user feedback.

The field of serious games is still a very young one and will require new theories and approaches as well as considered adaptations of proven methodologies for design, development, and assessment. Instructional Ethology is one such adaptation that can lead to new insights about how games and game technology support learning. Integration of the game's behaviour with its morphology is essential for effective instructional support.

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