Deep Learning Games through the Lens of the Toy

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Abstract

Much has been written in recent times about game-based learning with the aim to bring together elements of game design and instructional design to make education more engaging. Sadly the results have been rather hit-and-miss and most educational games fail to either entertain or educate. Yet there are many entertaining computer games which exhibit all the characteristics of well-designed educational tools. Can these tools only be used to teach combat or dangerous driving? Or is there another reason why educational games fail where entertainment games succeed?

Schell's "Lens of the Toy" provides valuable insight into this problem. An engaging game is based around an interesting toy, something that is already fun to play with before goals, challenges and narratives are added. A good toy is a complex system with many affordances that engage cognitive abilities of pattern recognition, strategic reasoning and problem solving. In an educational game, we argue this toy should be a concrete model of the learning domain. Such a toy can support all the requirements Gee has set out for teaching "deep conceptual understanding". Without such a toy at its core, educational games are likely to be little more that shallow, didactic, "skill-and-drill" exercises with a coating of irrelevant gameplay to make them palatable.

Keywords: games-based learning, game design, emergence, game feel

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Introduction

Bodily exercise, when compulsory, does no harm to the body; but knowledge which is acquired under compulsion obtains no hold on the mind ... Do not use compulsion, but let early education be a sort of amusement; you will then be better able to find out the natural bent.

Plato, Republic, Book VII 380 BC

There is an obvious affinity between play and learning that has been noted by teachers and scholars since Plato's day. Play is recognised as a fundamental source of childhood education and there is a significant community of scholars who believe that a playful approach to learning can also help engage adult students.

With the flourishing of the modern computer game industry, many educators look with some jealousy at the amount of time students, both young and old, dedicate to games instead of to their studies. Computer games are clearly highly motivating, but attempts to harness this motivational power to serve educational goals have been rather hit-and-miss (Ke, 2009). This should not surprise us; the craft of game design is still in its adolescence and we are only just beginning to understand the rules and processes of good design. There are as many poor entertainment titles as poor educational games, and few (if any) educational projects receive the same budget as a triple-A commercial title. A mixed quality is to be expected, but there is always room to learn from our mistakes and improve.

Surveying a range of recent educational games from the 2011 International Serious Play Awards¹, we have noticed a significant failing across many games. They attempt to marry traditional didactic learning methods (instruction and quizzes) with unrelated gameplay, which is just there to "make learning fun". The result is "chocolate-coated

¹http://www.seriousplayconference.com/2011-awards/

broccoli" – an antagonistic relationship between fun and learning that is neither palatable not nutritious (Habgood, 2009).

This approach fundamentally misses the value of gameplay as a communication medium in its own right, i.e. what Bogost calls *procedural rhetoric*, the ability for an interactive process to convey a message (Bogost, 2007). Gameplay should be more than just a distraction from the drudgery of learning. It is a means to provide first-hand experience of systems and processes and understanding of the forces that govern them.

The didactic approach to educational game design misunderstands the relationship between learning and fun. We should not have to "make learning fun". Learning, when experienced well, is *intrinsically* fun. One of the primary factors that engage us in any game is the opportunity to learn, through uncovering patterns in systems and mastering skills (Koster, 2004). This is not the rote learning of didactic instruction but active, experiential learning in which knowledge is constructed, refined and applied through concrete experience.

From a designer's point of view, we diagnose this disconnection between gameplay and learning content to ultimately be due to a gap in the discussion of design for games-based learning. While many have addressed issues such as challenge, control, mystery and fantasy (e.g. Malone, 1980; Malone and Lepper, 1987; Garris, Ahlers, and Driskell, 2002; Whitton, 2011), there seems to have been little discussion of the system at the core of the game, the "toy" with which the game is played. In this paper, we aim to consider what Schell calls the "Lens of the Toy" (Schell, 2008):

To use this lens, stop thinking about whether your game is fun to *play*, and start thinking about whether it is fun to *play with*.

Ask yourself these questions:

- If my game had no goal, would it be fun at all?
- When people see my game, do they want to start interacting with it, even before they know what to do?

A good game, we argue, is based around a good toy. The toys that we describe are not childish playthings but complex, embodied systems which engage our pattern recognition systems and provide a wealth of affordances for playful interaction. This toy provides the core mechanics of the game and is fundamentally what the game is *about* – it is the part of the game the player spends most of their mental effort on. A game may be wrapped in an interface and story that depict any topic you like, but if the toy at the heart of the game is, for example, a side-scrolling platformer then the game is about jumping and collecting points, no matter what the wrapping might show or say.

Our key recommendation for games-based learning is therefore this: the toy at the heart of an educational game should be a concrete model of the system that governs the learning topic. The student should be invited to play with and explore this system, to learn its patterns and master its control. Abstract concepts to be taught should arise intrinsically through guided play rather than being extrinsically enforced on the game. By this means we engage what Gee describes as "deep conceptual learning" (Gee, 2009).

In what follows, we look more closely at the theory of experiential learning and the qualities that Gee describes as important for deep learning. We draw out three key themes – *abstraction, control* and *ownership* – and relate them to the Lens of the Toy through the design principles of emergence, game feel and expressive play.

Deep Learning

To know how to make games that educate we need some understanding of how people learn. For the sake of this article, let us focus on conceptual learning – learning ideas and concepts as opposed to learning manual skills, although we will find that the two can never be completely dissected from each other.

The traditional academic approach to conceptual education is didactic; a process of instruction and examination (Figure 1). An expert instructor explains the ideas, usually verbally (possibly with the aid of demonstration). Students memorise these ideas and repeat them back to the instructor in assessment tasks such as examinations. Some tasks may also include an element of implementation, students using the taught concepts to solve problems, but they focus on the application of received knowledge rather than testing knowledge and uncovering new ideas.

Many educational games embrace this methodology. Consider for instance the game *Treadsylvania* from New Mexico State University, a silver medal winner at the 2011 International Serious Play Award Conference Competition. More an interactive comic book than a game, it makes the ideas it is teaching quite explicit. Figure 2(a) shows a scene in the game which attempts to teach the dangers of riding an ATV (quad-bike) on the road. The danger is outlined quite explicitly in the text. The player is then given an opportunity to show they have understood by completing a mini-game in which they have to scare away imps which try to force them onto the road. If the player strays too far onto the road, the game responds with an unequivocal message of failure (Figure 2(b)). This is what we term a 'didactic' game, a game which teaches by presenting ideas directly to the player (usually in text) and then testing them on their understanding. This does not make for very engaging gameplay. It fails to provide what Sid Meier calls "interesting choices" (quoted in Alexander, 2012). The choices the player makes contain no conflict and no room for personal play style.

Gee disparages this kind of "skill-and-drill" learning as shallow and calls for an approach to education that engages the student in the entire knowledge creation process. Ideas do not simply exist in a vacuum. They are abstract generalisations of a concrete reality, created out of need to solve problems. Deep conceptual learning occurs when ideas are situated within a concrete task and driven by personal goals. An alternative formulation of the *Treadsylvania* scenario would be to implement the dangers of road-driving as mechanics of the game. A player who is given the task of driving home will soon realise that avoiding the asphalt is a safer way to reach their destination, even if it is a little slower. This would be a more interesting choice because it would be a trade-off between speed and safety.

In making these claims, Gee is drawing on the theory of experiential learning introduced by David Kolb (1981). This is a theory of learning that explicitly recognises this duality between concrete experience and abstract concepts. It represents learning as a cycle (Figure 3). Learning begins with concrete experience of some domain. By observations and reflection on the experience, learners create new abstract concepts. Active experimentation with these concepts leads to new concrete experiences that confirm or refute the ideas. These processes of reflective observation and active experimentation parallel Piaget's notions of accommodation (adjusting our mental models to fit new experiences) and assimilation (using our mental model to understand unfamiliar experiences).

Didactic methods only embrace half of this cycle. They start with abstract concepts and only venture as far as controlled concrete implementation of those concepts. Concrete experience is usually only provided after the fact, to confirm the ideas taught, rather than to prompt new ideas or challenge existing notions.

Experiential education is a philosophy of teaching that attempts to guide the student through the entire learning cycle of discovery, generalisation, and experimentation. Active engagement in the process of knowledge creation is more engaging and more liking to result in knowledge retention (Gee, 2007). As the familiar proverb states: "Tell me and I'll forget; show me and I may remember; involve me and I'll understand."

This would appear to be where the power of games and education coincide. Games are fundamentally systems and play is about exploring those systems, discovering the dynamics that drive them and mastering control over them (Koster, 2004). If games-based learning is to work at all, it is through providing players with concrete experience of systems as a platform for experiential learning, rather than by "gamifying" the learning experience with points, achievements or other artificial rewards.

How do we design to support deep learning? Gee identifies a list of qualities of 'good games' that make them suitable. Rather than go into his list in detail, we identify three

core themes:

- Abstraction The game implements a concrete system with an abstract interpretation. Thus it engages the player's cognitive modelling processes and it can be an experiential learning experience.
- **Control** The game provides a tool for interacting with this concrete system with a rich set of affordances for manipulating the world at a fine-grained level. This engages our innate ability to assimilate tools into our body image and use them intuitively.
- **Ownership** The game allows you to create your own personal narrative of your learning experience, providing a greater sense of personal attachment to learning.

Let us investigate each of these in more detail and consider how they can be understood through the Lens of the Toy.

Abstraction

Conceptual learning is fundamentally about recognising useful abstract patterns in a concrete system, such as the rules of multiplication (which generalise the behaviour of all numbers) or of grammar (which generalise over words and sentences). In education we deal so often with these abstractions that it is often easy to lose sight of the concrete reality from which they arise. A game can depict these concepts in their rightful place, as patterns that intrinsically emerge from the operation of a system rather than as moulds externally forced upon it.

This is the first role of the toy, to implement a model or simulation of the learning topic. The system should invite an abstract interpretation but not force it. So for example, an economics game might be designed to convey the law of supply and demand – that the price of a good in a market settles to an optimum value at which the demand for the good equals the supply. If we implement this law directly and a rule of the game then we state it as a given fact and provide no opportunity to engage players' pattern recognition skills to

uncover it. If however, we implement a system of agents, buyers and sellers, adjusting their trading behaviour over time to maximise their returns, then the law of supply and demand will emerge intrinsically from their behaviour without ever being explicitly coded. Players of this game can discover this pattern and test its generality in a variety of circumstances. Their understanding of the idea is better grounded in experience.

There is some reason for hesitation at this point. Emergent gameplay is a widely admired property of games but it means giving up some authorial control (Juul, 2002; Sweetser and Wiles, 2005; Dormans, 2012). Externally imposed patterns can say exactly what we want them to say, but intrinsic patterns rely on the vagaries of the system, including the behaviour of the player. It is hard to design a system that allows complexity yet reliably produces the abstract outcomes we desire.

Since the model is never a precise representation of reality, emergence can result in pathological behaviours and unintended patterns that have no real-world counterpart. For instance, in the physics-based game *Armadillo Run* certain inaccuracies in the collision handling code allow the creation of perpetual motion machines which, of course, are impossible in the real world. Players' reactions to this possibility are mixed. Some players regard any behaviour supported by the game as legitimate and make widespread use of this feature in their designs. Other players look on this behaviour as 'cheating' and voluntarily limit themselves to not take advantage of this 'bug'. A problem such as this may not matter in an entertainment title (as *Armadillo Run* is) but would be more significant if the game was intended to teach the laws of physics.

We can never guarantee that such pathologies will not arise without oversimplification and artificial constraints on the player, but the worst cases can be avoided by ongoing playtesting. This issue highlights the need for learning games to be used in a wider educational context where in-game concepts can be tested against the real world.

A more substantial problem is the lack of a computable concrete model in the first place. For domains with well established numerical models, such as physics or economics, this is not an issue, but in other domains it is significant. Consider for instance the problem of using games to teach ethics. An ethical scenario engages one-on-one social skills including awareness of the problem, sensitivity to different points of view and carefully nuanced decision-making. Making a concrete model of this system is well beyond our understanding and as a result most ethical simulations work directly at the abstract level. All sensitivity and nuance is lost when the problem is presented directly and the possible resolutions are listed as a multiple choice question. This appears to be a fundamental limitation of experiential games-based learning.

Control

Experiential learning is inherently interactive. While the learner engages in ideation and problem solving at the abstract level, it is important that solutions are implemented in a concrete reality. The tools we provide to interact with the problem domain should provide a variety of affordances to manipulate the domain at the concrete level.

Fine-grained control (Gee calls it *microcontrol*) engages our tendency to assimilate tools into our body image and use them intuitively (Clark, 1997). Thus, as experienced drivers, a car is not a machine that we use but an extension of our self with which we affect the world. Our sense of personal space expands to include the entire vehicle and the sounds and vibrations it makes feed directly into our sense of whether we are driving well. So a novice driver may have memorised the functions of the various pedals and levers but the experienced driver knows them by feel. The advantage of this kind of embodiment for learning is that it allows us to intuitively ground our knowledge in reality.

As well as embodiment, microcontrol also allows nuance. Where extrinsic abstract choices are presented in games, they are usually discrete and relatively few, whereas a concrete system can present a continuum of alternatives each with slight variations of the control parameters. Compare, for instance, navigation in a text adventure with navigation in a first-person shooter. In the former, navigation choices are abstract and discrete: the player can choose to go north, south, east or west. The action will take them to the next room, but allows no control over how they travel, slowly or quickly, cautiously or boldly. The outcomes of each choice are explicitly coded on a case-by-case basis, so they are relatively few – coding explicit cases for "crawl north cautiously" and "run boldly east" would be too time-consuming for the designer and would be tiresome for the player to explore.

In a first person shooter, the player has microcontrol over their movement from moment to moment, selecting speed and direction from a wide range of values. The game's response is computed by a continuous numeric model rather than a collection of discrete cases, so a much wider range of outcomes are possible. As a result, there is room for mastery. Around any intended action there is a neighbourhood of more or less correct outcomes. As the player gains skill in manipulating the system, they can produce precise, nuanced and expressive play. This process of mastery can be highly engaging.

A richly complex system also means that no two games need be exactly alike. Similar patterns will arise from one play-through to the next, but the details will be different, keeping the experience fresh. Extrinsically imposed abstract choices, on the other hand, betray the hand of the designer. They feel forced and the player feels less ownership of their actions as they have clearly been written by another. Replaying such a game is limited to exhaustive enumeration of the scripted alternatives. The consequences are usually shallow as authoring large amounts of extrinsic material is costly and time-consuming. Once the "correct" alternative in any abstract choice is known, there is no incentive to practice it again or investigate the other outcomes. The replayability of a good game significantly improves its teaching value, as the player can experience many variations of the same abstract concepts in different circumstances.

Ownership

Ultimately the aim of experiential learning is to instil a sense of ownership in the learner of the things they have learnt. Knowledge gained by our own discovery and used to solve our own problems becomes part of our personal story and is therefore more valuable and more readily retained. Knowledge taught didactically belongs to the teacher, and while students may parrot it back to them they do not fully grasp it until they can make it their own.

The sense of embodiment that is realised through concrete control makes knowledge personal. Mastering the nuanced control of a system creates opportunities to express personal style in the way we solve problems, in the same way that a handwritten letter can show more personality that an SMS message. Ownership of ideas and creative engagement with them are two of the most valuable outcomes of learning.

When students feel ownership of ideas, they are more inclined to share them with others, which in turn leads to stronger learning. To communicate an idea one has to establish it more clearly in one's mind and faces the criticism of others with conflicting ideas. Many games support this drive to communicate by connecting with social media. *SpaceChem*, for example, allows the player to construct elaborate chemical factories. When a factory is complete, a video of its operation can be posted to YouTube to share with other players. These videos can be used to illustrate clever techniques and are a useful learning resource for newer players.

Designing for deep learning

As we have described, we believe that learning is most effective and most enjoyable when the learner is actively involved in the pattern discovery process. A concept that has been learnt from personal experimentation in the pursuit of personal goals is a source of pride and will stay with the learner longer than something they were merely told. Games can provide this experience, but to support this kind of learning, the abstract concepts we want to convey should be expressed as intrinsic patterns emerging from a lower-level concrete system. Such a system promotes experiential learning and engages the player by providing more scope for discovery and mastery.

How then do we design such games? By no means can we offer a foolproof process, but here are some steps that we have found useful in our own process:

1. Identify a fine-grained model of the mechanics and dynamics of the real-world system.

2. Present the system to facilitate the recognition of patterns.

- 3. Provide a tool for embodied, playful control.
- 4. Add goals to stage the player's exposure to the system.
- 5. Provide support for social sharing of expertise.

Step 1: Identify a fine-grained model of the mechanics and dynamics of the real-world system.

As we have stated above, the toy at the heart of an educational game should be a concrete model of the dynamics of the real world domain where this is possible. The model should be implemented at a finer level of detail than the concept we aim to communicate, so that these concepts arise as emergent patterns.

The level of detail of this model is an issue. With too little detail our system will no longer be emergent and we run the risk of being didactic. Too much detail, however and the concepts we aim to teach may be lost in the noise. Our goal is to reveal the important patterns without stating them outright. The game need not be realistic in a one-to-one isomorphism with the real world, but they must have the same core behaviours revealing the same emergent patterns.

Dormans discusses different kinds of model which are useful here (Dormans, 2012). He distinguishes *indexical* and *symbolic* simulation. Indexical simulation reduces a large number of similar factors in a model to a representative set. So, for instance, *Sim City* does not distinguish particular kinds of businesses in a society, it simply classifies land use as residential, commercial or industrial with high, medium and low density. The important dynamics of the system are preserved while the detail is only presented cosmetically and has no effect on gameplay.

The alternative is symbolic simulation. In this case a different, non-representative mechanic stands in place for a realistic one, usually for the sake of simplicity. So for example battles in *Risk* are resolved by rolling dice. Randomness is understood to represent the vagaries of war. This is satisfactory as long as it does not create any unwanted dynamics, but can be misleading if the dynamics of the symbolic model are too far from reality. For instance, the grid-based inventory system in *Diablo* is understood to be symbolic of managing the weight and bulk of a pack full of equipment, however it is blatantly unrealistic. A metaphor is only useful if we understand how it transfers to the reality. If we move too far away from realism a game can lose its attachment to the real world and become just an abstract set of rules. It may still be an engaging experience, but it no longer teaches anything about the bigger picture.

Symbolic simulation can exacerbate this problem. Consider, for instance, the game SpaceChem. The chemistry in this game is almost entirely symbolic. While the basic ideas of atoms, molecules and bonding are present, the way they are mechanically represented is wholly unlike the true mechanics of chemistry. As such it is unlikely to be of much benefit in teaching chemistry, despite being a very engaging game.²

Our ability to create a fine-grained model of our learning domain is the biggest limitation of experiential games-based learning. It is often assumed that any topic can be taught this way, but for a large number of topic areas we have only a vague understanding of the forces that underly the patterns we observe. This is particularly the case when we address social rather than physical systems. Even in well understood systems such as

 $^{^{2}}$ It should be noted that the stated teaching aims of this game only include a passing reference to chemistry. The principle aim of the game is to teach notions of computer science (Zachtronics, 2012).

chemistry, creating a system that produces all the chemical properties we commonly observe would mean including a plethora of special cases, or else modelling a lot of complex molecular physics. We need to accept that games-based learning may not be suitable to every topic.

Step 2: Present the system to facilitate the recognition of patterns

The design of the interface, the way in which the system is depicted, has significant effect on our ability to recognise patterns. Consider for example the following game³: Nine cards are laid face up on the table, with numbers from 1 to 9. Two players take turns choosing a card to add to their hand. The aim is to make a set of three cards that add to 15. The first player to make this set wins. What is a good strategy for this game? If you have not encountered it before, spend a moment thinking about how you would play before proceeding.

It turns out that this game is mechanically isomorphic to a much more familiar game: tic-tac-toe. If the cards are arranged in a magic square, then every row, column and diagonal will add to 15. Drawing a card is equivalent to placing a nought or cross in the corresponding cell. The two games are equivalent but tic-tac-toe is a much easier game because it engages our spatial pattern recognition.

People are much better at intuitively grasping perceivable physical quantities such as position, size, speed and colour than they are at understanding numbers. This is especially true when it comes to recognising abstract patterns. A graphical or physical model of a system is often a good way to engage these intuitions when the real system is more conceptual focus. An example is the common hydraulic model of electricity which depicts electrical currents in circuits as water flowing through pipes (Esposito, 1969). The *iCircuit* simulator for the iPad uses this technique to make visible the abstract notions of current and voltage (Figure 4). Colour and animation make circuit dynamics much easier to

³This example is taken from *Half-Real* (Juul, 2055)

recognise and understand.

Contrast this with *Fate of the World*, a game about world environmental economics (Figure 5). There is a large amount of concrete data underlying its model and much of it is presented to the player as tables of statistics such as the only shown. Numbers are an abstraction and they don't relate to embodied experience of the world. The don't allow us to use our knowledge of being in the world to help understand the model, and so they come across as daunting and impenetrable.

While making patterns more easily recognisable is useful, there a fine line between making the patterns apparent and doing the pattern recognition for the player. We must avoid drawing explicit boundaries in continuous data to indicate the presence or absence of a particular pattern. It is better to let the player see the data in all its complexity rather than detect the patterns for them, or else the opportunity for experiential learning is short-circuited.

Step 3: Provide a tool for embodied, playful control.

Just as our pattern recognition abilities are most easily invoked through sensory embodiment, so also our sense of control is most intuitive when it has a consistent physical interpretation (Norman, 2002). The sense of embodiment that Gee recommends for learning games is understood by designers as *game feel*, the "kinesthetic sensation of control" (Swink, 2008). It is created through real-time control of an avatar (an simulated physical body, not necessarily a person) through a depiction of space. The uninterrupted flow of command and feedback from the world is important in maintaining this feeling. When successful it gives the sense of the avatar as an extension of the self interacting with a consistent physical reality.

There is, however, a limit to how widely achievable such an experience of embodiment is. Real-time control of an avatar is perhaps only suitable for a minority of learning topics. It is hard to see how this might be applied to a large-scale economic simulation, for example, or an electrical circuit. Such topics might be more suited to strategy or puzzle games. Gee admits that such games "widen vision, perhaps at the cost of intimacy" but doesn't otherwise discuss how this affects their learning value.

Regardless of whether real-time control is achievable, it is important to design a tool that is at once simple but provides multiple affordances for nuanced interaction with the system. Consider the most enduring toy of all time: the ball. It does not have a wealth of features and functions and yet it offers a rich set of behaviours based on how it is thrown – with force, direction and spin – and how it subsequently interacts with the world. The whole system of ball-and-world is complex but the ball itself is simple. The variety comes not through selecting one of many features, but through careful tuning of the parameters of the throw. A master player knows how to impart just the right amount of force or spin to achieve the effects she wants.

This seems typical of all the best toys, from a ball to a car to a portal-gun. They have a few functions with a small set of continuous control parameters such as the force and spin of the ball. Complexity comes from the exact choice of these parameters and the toy's subsequent interaction with the world. This is possibly the most difficult thing to design and we know of no sure-fire way to achieve it other than iterative prototyping and playtesting with a constant eye for the playfulness of the toy.

Step 4: Add goals to stage the player's exposure to the system

While free play is valuable, it becomes directionless without goals. A large and complex system can present too much information at once. Without the basic ideas with which to break down this information into manageable patterns, the learner can be overwhelmed. Instead, the learner should be exposed to the "optimal level of informational complexity" (Malone, 1980) so that the game is neither completely incomprehensible, nor completely predictable. The object is to engage the learning cycle of assimilation and accommodation and maintain the player's curiosity. Concepts should be revealed incrementally, each one allowing the player to make further progress in the game and building on each other to provide a more sophisticated understanding of the system.

This incremental revelation can be achieved through level design. Early levels of the game constrain the player to work with only a subset of game features and present goals that are achievable within this context. This allows them to acquire and practice new ideas and skills in isolation before using them in a larger context. Care must be taken, however, not to force the player's hand. There should always be room for play.

While new concepts can be taught in isolation, the player should also be given an opportunity to integrate them into their larger skill set. After a skill has been practiced, the player should be presented with a task that requires new skills to be combined with those already mastered in non-obvious ways. The richness of an emergent system often means that concepts overlap and interact, and a real problem cannot be neatly divided into independent subproblems.

The game *Portal* does a remarkable job of this. The player is lead through a series of "testing chambers" each of which presents a clear goal and a new concept or technique that would be used to achieve the goal. Subtle hints are given to guide the player towards certain solutions by attracting their attention to important objects or by demonstrating an effect before having the player imitate it, but never is the player told outright what they need to do. Each chamber provides multiple opportunities for the player to practice the new skill before proceeding, but practice is kept from being repetitive by creative use of variations. Each learnt skill is also tested as part of a larger complex problem where the application of the skill is not immediately obvious.

Step 5: Provide support for social sharing of expertise.

To this point we have considered learning games mostly from a single-player perspective, but there are benefits for both education and engagement in placing the game within a wider social context. Cooperation and competition are both strong motivating factors in games and being part of a community who are passionate about a topic motivates a student to become more involved and learn more about the topic.

Sharing knowledge between learners is also valuable, for both the one who receives and the one who gives. This might seem to be a return to didactic education, but in this instance knowledge is sought purposefully to solve existing problems and the exchange of knowledge goes in both directions, rather than from the privileged 'expert' to the 'novice'. Teaching others is a valuable learning experience in itself, as it requires the teacher to formalise knowledge that they might only tacitly understand.

Finally, communication is essential for transfer of concepts learnt in the game to the real world. The experiential learning cycle promotes the construction of abstract concepts, but they are focused on the game not the reality. The psychology of the 'magic circle' means that players are not likely to see the applicability of their newfound knowledge outside the game unless prompted (Leutner, 1993). Debriefing is easier when there is already an active community around the game. Learners are more likely to engage in discussion when they feel a personal attachment to their discoveries and achievements.

To this end, good game design goes beyond the single-player experience to the community of gamers. An active community encourages players to share their in-game discoveries and achievements. Ideally, the game should be integrated with the community in ways that facilitate this sharing. With the rise of social networking, especially video services such as YouTube, it is now possible for players to directly display their in-game achievements to one-another, as done, for example, in *SpaceChem*. The idea is not to just sharing scores and outcomes, but also to facilitate the exchange of knowledge.

Conclusion

We do not pretend that the process we have described is simple. Quite the opposite, we have deliberately set out to illustrate how hard it is to do this well. The games we have criticised are by no means carelessly made; a lot of effort has without doubt been put into their design and yet they fall short in many ways. The truth is that designing a good game is hard and designing a good educational game is harder still. This is a fact that is often overlooked in the literature. Good games appear effortlessly good. It is not until you make a game (and genuinely test it with an unbiased audience) that you discover how difficult they are to produce.

Slapping an arbitrary game-like structure on top of traditional didactic teaching methods has limited utility. When learning and fun are in contention the educational parts of the game are often resented as obstacles in the way of the entertainment. Arbitrary extrinsic rewards provide temporary motivation but lead to over-justification and a loss of interest in the long term.

It does not have to be this way. Exploration, discovery and mastery are all fundamental aspects of what makes games fun. It should be possible to harness these same aspects to engage learners in more serious topics but to do so we need to abandon didactic teaching and embrace an experiential model of education. Games should be meaningful models of real-world systems, which provide room for abstraction, control and ownership. The learner should be given the opportunity to discover patterns that emerge intrinsically from the system rather that having them externally imposed. They should have the opportunity to play with the system and master its manipulation, and they should be given the opportunity to own their discoveries and share them with others. Designed well, such games promise to a be more engaging and more effective learning tool.

However this design is not a simple matter. It involves detailed understanding of the low-level mechanics of our learning domains and an understanding of how they might be represented with the right measure of simplicity, revealing patterns piece by piece without enforcing them. The Lens of the Toy is an important guide here. The aim is to make the learning topic a fun device to explore and play with. By leaving room for play we promote discovery, mastery and expressive play which lead to greater engagement with learning and ownership of the resulting knowledge. This Lens also highlights a major difficulty: for some disciplines this toy is poorly understood. We simply do not have computable fine-grained models of ethics, or architectural design, or language. Even in the hard sciences, chemistry and biology are much harder to represent than physics. Most of our knowledge in these domains exists only at the abstract level. In this case, creating the "toy", a concrete simulation of the learning domain, is beyond us.

Games offer great benefits for experiential learning but those benefits do not come for free; it takes significant skill and effort. We hope the advice offered in this article will help others making such games and further realise the promise of engaging learning through play.

Works cited

Armadillo Run by Peter Stock, Daniel Jackson. http://www.armadillorun.com/

Diablo by Blizzard Entertainment.

Fate of the World by Red Redemption. http://fateoftheworld.net/

iCircuit by Frank Krueger. http://icircuitapp.com/

Portal by Valve Corporation.

Risk by Parker Brothers.

Sim City by Maxis.

SpaceChem by Zachtronics Industries. http://www.spacechemthegame.com/

Treadsylvania New Mexico State University's Learning Games Lab. http://treadsylvania.com/

References

- Bogost, I. (2007). Persuasive Games: The Expressive Power of Videogames. Cambridge, USA: MIT Press.
- Clark, A. (1997). Being there: Putting brain, body and world together again. Cambridge, USA: MIT Press.
- Dormans, J. (2012). Engineering Emergence: Applied Theory for Game Design. (Doctoral dissertation, Universiteit van Amsterdam).
- Esposito, A. (1969). A Simplified Method for Analyzing Circuits by Analogy. *Machine Design.*
- Garris, R., Ahlers, R., & Driskell, J. E. (2002). Games, Motivation and Learning: A Research and Practice Model. Simulation & Gaming, 33(4), 441–467.
- Gee, J. P. (2007). What Videogames have to teach us about learning and literacy. Basingstoke, UK: Palgrave Macmillan.
- Gee, J. P. (2009). Deep Learning Properties of Good Digitial Games. In Serious games: mechanisms and effects. New York, USA: Routledge.
- Habgood, J. (2009). Wii don't do "Edutainment"! In Proceedings of games-based learning. London, UK. Retrieved from http://www.gamebasedlearning2009.com/proceedings/video/905-video/206-dr-jacobhabgood-head-of-serious-games-sumo-digital
- Juul, J. (2002). The Open and the Closed: Games of Emergence and Games of Progression. In Frans Mäyrä (Ed.), Computer cames and digital cultures conference proceedings (pp. 323–329). Tampere: Tampere University Press.

Alexander, L. (2012). GDC 2012: Sid Meier on how to see games as sets of interesting decisions. *Gamasutra*. Retrieved from http://www.gamasutra.com/view/news/164869/GDC_2012_Sid_Meier_on_how_ to_see_games_as_sets_of_interesting_decisions.php

- Juul, J. (2055). half-real: Video Games between Real Rules and Fictional Worlds. Cambridge, USA: MIT Press.
- Ke, F. (2009). A qualitative meta-analysis of computer games as learning tools. In
 R. E. Ferdig (Ed.), Handbook of research on effective electronic gaming in education (Vol. 1, pp. 1–32). Information Science Reference.
- Kolb, D. A. (1981). Learning styles and disciplinary differences. In *The modern american college*. San Francisco, USA: Jossey-Bass.
- Koster, R. (2004). A Theory of Fun. Phoenix, USA: Paraglyph Press.
- Leutner, D. (1993). Guided discovery learning with computer-based simulation games: Effects of adaptive and non-adaptive instructional support. *Learning and Instruction*, 3(2), 113–132.
- Malone, T. W., & Lepper, M. R. (1987). Making learning fun: A taxonomy of intrinsic motivations for learning, (Vol. 3, pp. 223–253). Lawrence Erlbaum Associates.
- Malone, T. W. (1980). What makes things fun to learn? Heuristics for designing instructional computer games. In Proceedings of the 3rd acm sigsmall symposium and the first sigpc symposium on small systems. New York, USA: ACM.
- Norman, D. A. (2002). The Design of Everyday Things. New York, USA: Basic Books.
- Plato. (1908). The Republic. Trans. B. Jowett. The Internet Classics Archive. Retrieved from http://classics.mit.edu/Plato/republic.html
- Schell, J. (2008). The Art of Game Design: A Book of Lenses. Waltham, USA: Morgan Kaufmann.
- Sweetser, P. M., & Wiles, J. H. (2005). Scripting Versus Emergence: Issues for Game Developers and Players in Game Environment Design. International Journal of Intelligent Games and Simulation, 4(1), 1–9.
- Swink, S. (2008). Game Feel: A Game Designer's Guide to Virtual Sensation. Waltham, USA: Morgan Kaufmann.

- Whitton, N. (2011). Game Engagement Theory and Adult Education. Simulation & Gaming, 42(5), 596–609.
- Zachtronics. (2012). SpaceChem: a Guide for Educators. Retrieved from http://www.spacechemthegame.com/education



Figure 1. The roles of abstract concepts and concrete experience in didactic education.

LOOKS LIKE THE QUARRY IS SAFE! WE BETTER BE ON OUR WAY.	HMMMWE COL THE ROAD OUT C	ULD TAKE OF HERE	THE TRAIL.
IT MIGHT SEEM FAST	ER	B	NOT SAFE!
			(item)

(a) Concepts about road safety are presented verbally.



(b) The player is tested on their knowledge of the concept.





Figure 3. The roles of abstract concepts and concrete experience in experiential education.



Figure 4. An electric circuit in iCircuit. The wires and components are colour-coded green and red to represent positive and negative voltages. Moving yellow dots represent electrical current.



Figure 5. One of more than a dozen pages of statistics describing the economics of single

country in Fate of the World.