Stealing from the Best: A Model of Video Game Learning Dynamics to Inform Instructional Design

Ian D. Beatty
University of North Carolina at Greensboro
Dept. of Physics & Astronomy, Box 26170, Greensboro NC 27402-6170 USA
idbeatty@uncg.edu, +1.336.256.8600 (voice), +1.336.334.5865 (fax)

Abstract: To facilitate the use of video game learning principles and dynamics in science teaching, I present a theoretical model that integrates ideas from a broad range of literature on video game design and video games as learning environments. It describes the essence of game play as voluntary engagement with a succession of challenges, powered by four dynamical loops: exploratory learning, identity growth, intrinsic motivation, and adaptive game response. Game play is a co-construction of the game mechanics and player, and much of a game's power to engage and teach arises from five different types of human-computer "meld" that the player can experience. The model describes coarse- and fine-grained elements of the game mechanics and their interrelationships, and can be applied at four different levels: the micro-level game as a succession of interesting challenges, the macro-level game as a designed experience, and two meta-level games focused on extending or modifying game aspects and on social interactions within and surrounding the game.

Keywords: Game-based learning; Instructional design; Intrinsic motivation; Mastery learning; Identity; Affect.

Introduction

Why should education researchers, instructional designers, and teachers care about modern video games?

Because they are popular. 183 million Americans self-identify as "regular" gamers, playing for an average of 13 hours a week. 97 percent of teens play. Despite persistent stereotypes, 40 percent of all gamers are women, and one out of four is over the age of fifty (McGonigal 2011).

Because they are important. They are emerging as a major literacy in our society, especially in the lives of our students (Koster 2005, p. viii, forward by Will Wright).

Because they are powerful. They have affordances far beyond those of other media for engaging, for persuading, and for educating (Bogost 2007; McGonigal 2011).

Because they already teach. Good video games are carefully engineered learning machines:

> Game companies face an interesting problem, a problem that schools face, as well: how to get someone to learn something that is challenging and requires persistence. (Gee 2007a, p. 2)
>
> The designers of many good games have hit on profoundly good methods of getting people to learn and to enjoy learning. They have had to, since games that were bad at getting themselves learned didn't get played and the companies that made them lost money.… These learning methods are similar in many respects to cutting-edge principles being discovered in research on human learning. (Gee 2007a, p. 29)

For those of us interested in improving science instruction, recognizing the learning potential of video games leads to three possible courses of action. One is developing games that teach science content and practice. While such a course is intriguing and promising, it should not be embarked upon lightly: Modern video games are developed by large and experienced teams with budgets upwards of a million dollars, and face very high expectations for production quality and sophistication. Furthermore, technology is an always-moving target, and the video game market evolves swiftly. A fully-developed instructional video game runs a severe danger of becoming old-fashioned soon after it has been completed.

A second course of action is to "gamify" standard instruction, dressing it up in the superficial trappings of games. Initial attempts in this direction may benefit from some novelty value, but such a shallow approach is unlikely to produce anything beyond shallow changes in students' learning.

A third course, which I advocate, is to learn from the design of effective video games and use what we learn to design novel approaches to classroom instruction: *game-informed learning* rather than *game-based learning* (Begg, Dewhurst, & Macleod 2008). Many of the "profoundly good methods of getting people to learn and to enjoy learning" that Gee refers to do not, in fact, depend on the electronic nature of these games (Gee 2007a).

Before attempting to design game-informed courses, we must first ask, "What are these 'profoundly good methods'? What are the deep learning principles embedded in the design of video games?" Learning scientists from a range of disciplines, as well as some of the more philosophical game designers, have addressed facets of this question. Their answers generally list principles, features, game characteristics, and the like, often conflating fundamental learning principles with useful game design tactics. While these lists are consonant or overlapping in various ways, they vary in their intent, their framing, their terminology, and the facets of games and the game-playing experience they address. This is problematic when trying to form a coherent "big picture" understanding of the topic.

I have synthesized this scattered literature into an integrated model of "games as learning systems" intended to clarify the critical elements and dynamics that underlie good games' remarkable power to engage and facilitate learning. The model's purpose is to serve as a useful guide

Submitted to the Journal of Science Education and Technology on June 7, 2014.

to the elements and dynamics that an educational experience should include in order to deeply incorporate game-based learning principles. The purpose of this paper is to present and explain the model, indicating its grounding in the literature on game design and game-based learning.

Background: Games and Learning

The literature on games and learning is varied, broadly scattered, and poorly interlinked. It can be grouped into four loose categories: treatises on effective game design; scholarly analyses of the instructional properties of games; reports on the design and testing of deliberately instructional video games; and reports on explicitly game-based and game-inspired courses.

Game Design

Based on Gee's observation that "The designers of many good games have hit on profoundly good methods of getting people to learn and to enjoy learning," it behooves us to consult practical works on game design written by and for game designers. Koster (2005) begins with a contemplation of what "game" means and what makes games enjoyable; much of the book is devoted to identifying the most essential mechanisms of games, stripped of superficial trappings, and examining the characteristics that make these more or less fun for players. Schell (2008) presents 100 different theoretical "lenses" for examining games, the game design process, and the game design profession. Many itemize the components of a game, or elements that must cohere to make it successful, or different game mechanisms that can engage players, or design flaws that can weaken games. Both Koster and Schell use their perspectives on game design to critique typical school-based education. Koster says, "One wonders, then, why learning is so damn boring for so many people. It's almost certainly because the method of transmission is wrong" (2005, p. 46). Schell says, "So, why doesn't education feel more like a game? The lenses in this book make it pretty clear… It's not that learning isn't fun, it is just that many educational experiences are poorly designed" (2008, p. 443).

Instructional Properties of Games

Several scholars have studied games *in situ*, analyzing the features that make them compelling and the affordances they offer for accomplishing tangible outcomes. McGonigal (2011) presents fourteen different ways in which games are "better" than reality. She observes that games can develop players' capacities for teamwork and social coordination, and advocates developing games to educate, improve people's lives, and solve real-world problems. Malone (1980a; 1980b; 1981), in a study of instructional games over thirty years old, examines the extraordinarily simple educational computer games of that era and points to intrinsic motivation as the key characteristic underlying their success. He identifies three mechanisms by which games provoke intrinsic motivation—challenge, fantasy, and curiosity—and presents a taxonomy of design strategies for implementing each. Steinkuekhler and collaborators (Steinkuehler & Chmiel 2006; Steinkuehler & Duncan 2008) use cognitive ethnography to study players participating in massively multiplayer online games, and find that player activity demonstrated "scientific habits of mind and dispositions," including social knowledge construction, evidence-based reasoning, and "an evaluative epistemology in which knowledge is treated as an open-ended process of evaluation and argument" (2008, p. 530).

Gee has offered the most comprehensive analyses of video games as learning systems, analyzing a range of games to extract 36 learning principles that developers employ (2007b) and then presenting a higher-level list of 13 principles underlying effective games (2007a). Taken together, these paint a compelling picture of how games function as learning environments and how they differ from conventional instruction.

Instructional Video Games

Squire warns that "the cognitive potential of games has been largely ignored by educators. Contemporary developments in gaming… suggest powerful new opportunities for educational media" (2003, p. 49). He and his and collaborators have developed and studied several different video games designed specifically to teach science content and process. These games have been narrowly focused on specific concepts or understandings and have been used to supplement, rather than replace, traditional instruction. Their experiments have involved augmented reality games with handheld devices in real-world settings to teach middle-school environmental science concepts (Squire & Jan 2007), simulations that let a player adopt the perspective of a charged particle to develop conceptual understanding of electromagnetism in university physics (Squire 2008), and the open-ended "sandbox" game *Civilization* to enrich middle-school students' understanding of history (Squire 2008).

Devlin (2011) applies Gee's original 36 principles to the domain of mathematics education. Comparing game-based learning to the way that children naturally learn "street mathematics" (Nunes, Schliemann, & Carraher 1993), he presents an argument and agenda for developing video games to teach mathematics. Like Gee, he presents a list of the "key features of gaming" that can inform game-based and game-inspired instruction.

The US National Research Council report *Learning Science Through Computer Games and Simulations* (2011) provides a broad summary of research into the development of games and computer simulations for teaching science. It concludes that "Evidence for the effectiveness of games for supporting science learning is emerging but is currently inconclusive. To date, the research base is very limited" (p. 2). It calls for researchers and developers to "describe the [game] design features that are hypothesized to activate learning, the intended use of these design features, and the underlying learning theory" (p. 3). This report clearly indicates the need for a comprehensive theoretical model connecting game design to instructional design, as presented in this article.

Game-Based and Game-Inspired Courses

So far, investigations into game-based and game-inspired in-person courses have been unsystematic and limited. Sheldon (2011) describes and reflects upon his own attempts to teach courses on game design as explicit games, and includes contributed essays on similar designs in other disciplines. All these attempts focus on grafting game-like structures and trappings onto fairly traditional instructional designs, for example by renaming homework assignments as "quests," quizzes as "monsters," exams as "level bosses," and points earned towards grades as "experience points." Some include team-based quests or increased player choice of assignments. While many of the reports indicate increased student engagement and generally positive results, it is unclear whether these result from novelty or from any deep shift in learning dynamics.

Jackson (2009) describes her attempts to incorporate game mechanics deeply into a course on technology for teaching. She asserts that "Leveling, 'well-ordered problems,' immediate feedback, resubmission, and discovery learning form the core of game-based teaching" (p. 296). She reports several difficulties, including a clash with students' notions of "school learning"; managing asynchronous student progress; and excessive student frustration.

Gorton and Havercroft (2012) describe their attempts to teach history through a course designed as a historical simulation game. Students were assigned roles to play in a simulation of a key historical event where deeply opposed world-views and interests conflict, and were responsible for learning the context of those events well enough to represent their character and faction. They found that the design increased both engagement and comprehension of the course content. However, they also noted a tendency for students to focus on winning rather than understanding the historical material, for example by mining period writings for argumentative ammunition rather than seeking to appreciate the author's perspective. This points to a potential danger for all game-like instruction: reframing students' intentions from "learning" to "winning."

Hestenes (1992) has portrayed science itself as a great game of "modeling" played against Nature, and has developed an approach called *Modeling Instruction* to teach high school physics students how to play that game. Brewe (2008) adapted the approach to university physics instruction. This represents the deepest and most authentic fusion possible of instruction and gaming, where the thing we want students to learn (e.g., doing science) is cast as the game itself. While provocative, this begs the question of whether the design principles used by modern video game developers might help us craft more effective courses, perhaps even *Modeling Instruction*-based courses.

In a similar vein, Malone says, "Computer programming itself is one of the best computer games of all" (1980b, p. 168). This suggests that courses incorporating content learning through students' programming of simulations, such as the *Matter & Interactions* physics curriculum (Chabay & Sherwood 2008), may be natural starting points for incorporating game design principles and game mechanics into instruction.

The Model

The works summarized above, and others similar to them, provide insights into how video games function as powerful learning environments and suggest ideas we might transfer into the realm of classroom science instruction. In this section, I present an integrated theoretical model developed from these sources. My effort has been synthetic, not generative. I have neither analyzed games nor studied game players, and cannot take credit for the individual observations that form the model's building blocks. My goal has been to discern how these various observations fit together into a logical, coherent, compelling whole. I call the result a "model" rather than a "framework" because the whole achieves more than mere taxonomy or description: it reveals something of the dynamics of a game—how the elements come together to make the magic happen.

The model describes games, looking at them through the lens of "learning systems." However, I intend it to be applied to other learning environments as well, in order to view those through the lens of "game design" and ask questions like, "In what ways does this learning environment or curriculum share the structural properties and dynamics of a good video game, and in what ways is it different?" The reader is encouraged to imagine how the model's constructs might be reinterpreted to apply to classroom-based or online courses.

The model is complex and multifaceted, because good games are complex and multifaceted. They get much of their power from synergies between different elements and processes operating on different scales, which the model must capture. In order to help the reader digest the model, I present it in stages. The reader is warned that some of the earlier stages present elements that might appear arbitrary until the full model has been unveiled.

I will first describe the model's coarse-grained structural elements, and then their fine-grained substructure. Next, I will present two kinds of dynamics contained by the model: "dynamical loops" that represent successive, cyclic interactions of its elements, and "human/computer melds" that represent simultaneous synergies of elements across the three spaces. After that, I will describe the four game "layers" or scales that the model can be applied to. Throughout, I will highlight some design principles implied by these structures and dynamics.

The Coarse Structure

The model's coarse-grained structure (the larger, shaded regions in Figure 1) captures a fundamental premise: that an effective game is an activity structure tightly coupling learning to intrinsically motivating experiences, through volitional and highly engaged activity directed at overcoming a series of problems (or challenges or obstacles or opponents). The player develops the necessary skills and knowledge through trial-and-error exploratory learning. A game offers the pleasure of mastering challenges, engages players in activities that are inherently rewarding, and promises that by learning to play the game better, more such experiences can be achieved.

Co-Construction

A "game" is a co-construction of the game architecture and the player. Schell observes that "The game enables the experience, but it *is not the experience*" (2008, p. 10). He grants that in any medium we can distinguish between the artifact and the consumer's experience of it, but argues

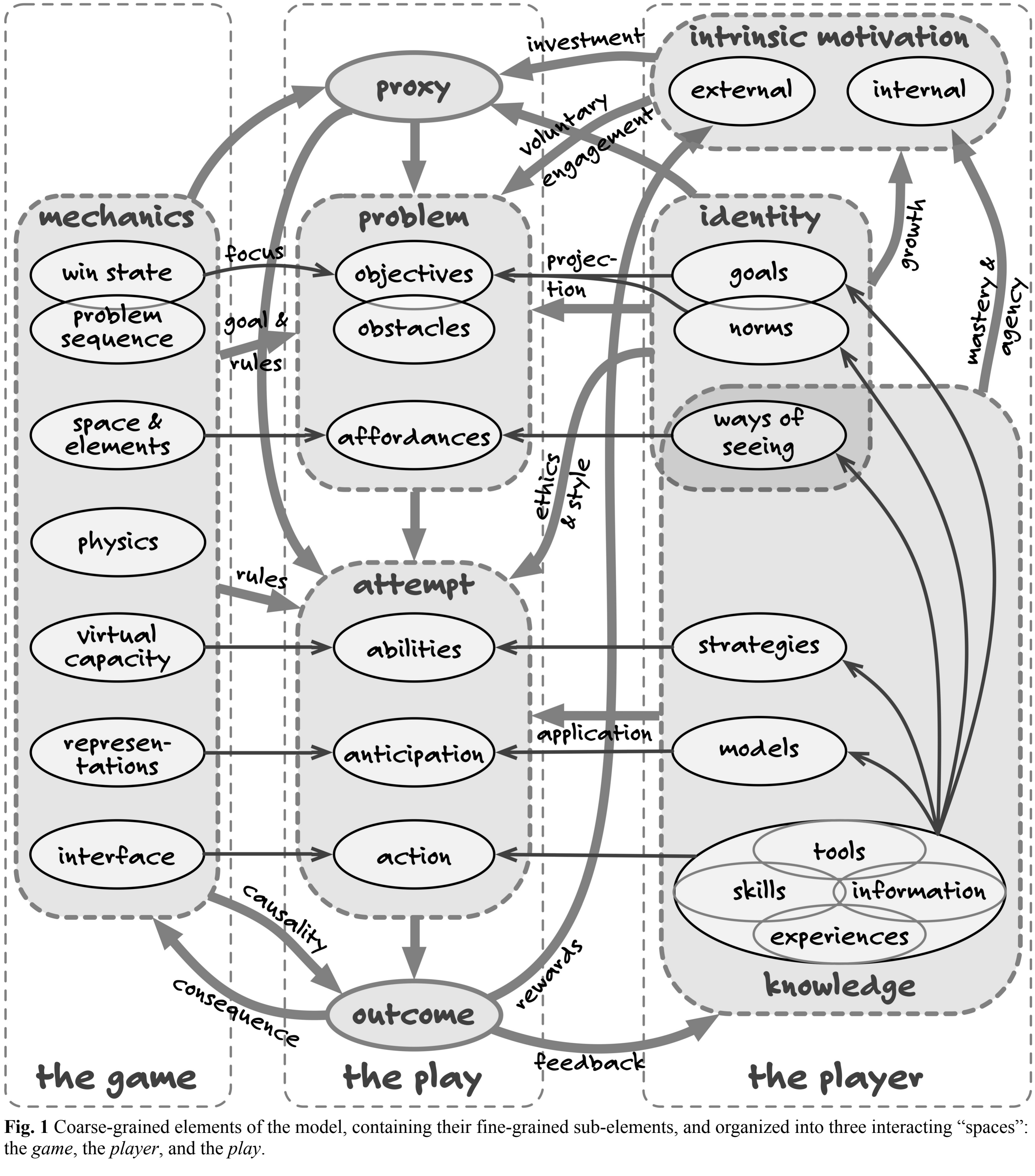

Fig. 1 Coarse-grained elements of the model, containing their fine-grained sub-elements, and organized into three interacting "spaces": the *game*, the *player*, and the *play*.

that "The split between artifact and experience is much more obvious for game design than it is for other types of entertainment… We give the player a great deal of control over the pacing and sequence of events in the experience" (p. 11). Player control often extends farther than just pacing and sequencing; Gee notes that many good games allow for a wide variety of play styles and strategies, leading to very different experiences (2007a). Schell continues, "What is so special about game experiences that we would give up the luxuries of control that linear entertainers enjoy?… To generate experiences that can be had no other way" (p. 12).

A key principle of game design—perhaps *the* key principle—is evident here: Players must have a sense of *agency*. Gee says, "Good learning requires that learners feel like active agents (producers) not just passive recipients (consumers)… People cannot be agents of their own learning if they cannot make decisions about how their learning will work" (2007a, pp. 30-31). In effective learning environments such as good video games, "There are multiple ways to make progress or move ahead. This allows learners to make choices, rely on their own strengths and styles of learning and problem solving, while also exploring alternative styles" (2007b, p. 105).

Accordingly, we begin our model with three interacting spaces: the *player*; the *game*, meaning the designer's product; and, co-constructed by these two, the *play*, meaning the setting imagined in the player's mind, the events that unfold, and the rest of the playing experience. Our model diagrams represent these as three rectangular frames containing and organizing the other model elements. We also articulate the *principle of agency*: "Players' choices should have significant consequences for the game world and the course of events within it."

Puzzles and Mastery

Games are sequences of problems to solve, puzzles to figure out, opponents to defeat, or other challenges to overcome, and the primary pleasure of game-playing arises from learning how to overcome them. Koster claims that "Games are puzzles to solve, just like everything else we encounter in life… The only real difference between games and reality is that the stakes are lower with games" (2005, p. 34). He also says, "Fun from games arises out of mastery. It arises out of comprehension. It is the act of solving puzzles that makes games fun. In other words, with games, learning is the drug [providing pleasure]" (p. 40). Schell says, "A game is a problem-solving activity, approached with a playful attitude" (2008, p. 37). Malone identifies the concept of *intrinsic motivation* as pivotal to understanding the power of games and to using them in the service of education (1980a; 1980b; 1981). Gee agrees, noting that "Humans and other primates find learning and mastery deeply, even biologically, pleasurable under the right conditions, though often not the ones they face in school" (2010, p. 47). He observes that in good games, "For learners of all levels of skill there are intrinsic rewards from the beginning, customized to each learner's level, effort, and growing mastery and signaling the learner's ongoing achievements" (2007b, p. 64).

Therefore, the model represents game play as a loop through a *problem*, an *attempt* made by the player, and a resulting *outcome*. The player's *proxy* is her in-game presence, which might be an abstract and disembodied perspective (e.g., "white" in chess); a specific visual symbol (e.g., a cartoon person); or a complex virtual persona with quantified attributes and a first-person point-of view (e.g., a character in an immersive role-playing game). She manipulates the proxy and brings *knowledge* to bear to engage with the problem, learning from the outcome of each attempt. She eventually develops the relevant knowledge to overcome the problem, which provides a sense of mastery that fuels *intrinsic motivation* and inclines her to engage with the game's next problem. This all implies the *principle of difficulty*: "The difficulty of challenges should be carefully tuned to avoid both frustration and boredom." As Gee says, "The learner gets ample opportunity to operate within, but at the outer edge of, his or her resources, so that at those points things are felt as challenging but not 'undoable'" (2007b, p. 68).

Identity

Effective games recruit a player's sense of identity, often in multiple ways and on multiple levels: as characters in the game, as players of the game, and as participants in a social community surrounding the game. Squire says, "Games require players to be active participants in co-constructing their worlds and identities with designers" (2006, p. 27), and, "Players develop new identities both through game play and through the gaming communities in which these identities are enacted" (p. 19). Gee observes that "Deep learning requires an extended commitment and such a commitment is powerfully recruited when people take on a new identity they value and in which they become heavily invested" (2007a, p. 32). Therefore, the model includes *identity* as an element of "the player," feeding intrinsic motivation and impacting the problems she chooses and the ways she attempts to solve them. We also suggest the *principle of identity*: "The game should invite players to adopt or construct an extended or alternative identity."

Game Mechanics

At the coarse-grained level, the model represents "the game" as a single element named *mechanics*. The game mechanics set the problem by specifying the goal to be achieved and the rules by which they may be achieved. They constrain attempts, and they impose the causality that determines outcomes—not just success or failure, but also details of how close to success the player came and why she missed. Finally, the mechanics respond to outcomes if the game adapts or reacts in any way to the player's actions and successes.

The Fine Structure

In order to analyze game learning dynamics in greater detail, we must identify constituent sub-elements of these coarse-grained elements (the inner detail in Figure 1).

Game Mechanics Model

Modern computer games are complex creations, inviting a huge range of possible taxonomic schemes for classifying their various parts and subsystems and properties and aspects and behaviors. Schell alone presents 100 different "lenses" (lists), each taking a different angle on games and game design (2008). Since my model is not intended to guide video game design, we will merely foreground the fine structure elements of "the mechanics" that play significant roles in the larger model.

According to McGonigal (2011), one of the four defining traits of a "game" is the existence of a goal: what the player must achieve to win. As Schell says, "Games have a lot of rules—how to move and what you can and cannot do—but there is one rule at the foundation of all the others: The Object of the Game" (2008 p. 148). In the model, I call this the *win state* of the game, to distinguish it from other kinds of goals. (Multi-stage games typically have a win state for each stage, building towards a final overall win state.) This element suggests the *principle of winnability*: "The game should have a clear win state that can be definitively achieved." This principle is not absolute, however: the objective of some games, like *Tetris*, is simply to delay defeat for as long as possible.

If games are fundamentally about solving problems for fun, it follows that a critical element of any game is the set of *problems* it poses and the *sequence* in which it poses them. Two of Gee's thirteen principles, "well-ordered problems" and "cycles of expertise," refer to the importance of problem sequencing for effective game learning and, therefore, for successful games (2007a).

Every game takes place in some *space*—physical, logical, and/or virtual—and involves interacting with some set of game *elements*—objects, environmental features, characters, and so on. A game problem can be conceptualized as figuring out how to move through the space and manipulate the elements in order to achieve the win state. In some games, the space and elements are simple and abstract, such as the grid and blocks of *Tetris*. In others, they simulate a rich and extensive virtual reality, such as the planet *Azeroth* in *World of Warcraft*. Despite the apparent diversity of game settings, however, Koster claims that all are "iconified representations of human existence," providing "concentrated chunks ready for our brains to chew on" (2005, p. 36).

The game's elements, situated within its space, behave in specific ways defined by the rules of the game. The model refers to these rules of behavior as the game's *physics*. In a simple game, the physics might specify how game pieces are allowed to move and interact. In a complex virtual reality game, it might be a pseudo-realistic physics engine that includes Newtonian motion, collisions, and fluid flow as well as the properties of technological devices, the ways one can manipulate them, and the results of such manipulations.

The game's rules also specify the player's options for moving through the game space and manipulating its elements. In some games, these are disembodied powers, such as moving game pieces on a virtual or physical board. In others, they are skills and abilities attributed to the player's proxy. In almost every game, however, the player is capable of in-game actions that she is not capable of in real life. The model refers to the set of things that the player's in-game presence can do as her *virtual capacity*.

A game's space and elements can be described logically in terms of their properties and behaviors, but they are presented to the player via specific *representations* (usually visual) that provide the imagery and support the setting, theme, and storyline of the game. Koster claims that games have two levels: the underlying formal abstraction and the fiction, metaphor, fantasy, or dressing that "clothes" them (2005). He argues that "Players see through the fiction to the underlying mechanics, but that does not mean the fiction is unimportant… The dressing is tremendously important" (p. 84). Malone claims that "fantasy" is one of the three aspects of games that promote intrinsic motivation (1981). Gee asserts that "Humans do not usually think through general definitions and logical principles. Rather, they think through experiences that they have had and imaginative reconstructions of experience… Good games can achieve marvelous effects here, making even philosophical points concretely realized in image and action" (2007a, p. 42). The game's visual representations are the ingredients of such imagery and imagination.

The bridge between the real world and the game world is the game's *interface*, "Where the player and game come together" (Schell 2008, p. 222). Through it the player perceives the game's representations of its space and elements and exercises her virtual capacity.

Intrinsic Motivation Model

Out of necessity, successful game designers are skilled engineers of intrinsic motivation. They must get players to enjoy playing their games and want to continue playing. To do so, they have discovered a range of general experiences players find rewarding, and have developed strategies for building games that foment such experiences. These experiences can be divided into two categories: "external" and "internal." Both are *intrinsically* motivating, meaning that the experience itself is the reward, rather than a means to gain a reward external to the game such as remuneration, social status, or academic success.

External intrinsic motivators arise from the game, external to the player. Examples include pleasing audiovisual aesthetics and spectacle; an entertaining story; surprise and discovery; humor; thrill and adrenaline; and, occasionally, physical movement (such as with *Wii*- and *Kinect*-based games). Koster says, "The core of gameplay may be about… learning puzzles and mastering responses to situations, but this doesn't mean that the other sorts of things we lump under fun do not contribute to the overall experience" (2005, p. 160).

Internal intrinsic motivators arise from within the player herself, triggered only indirectly by the game. That is, she is enjoying her playing of the game rather than (or in addition to) enjoying the game itself. The two most important are *mastery* and *agency*, because they form the backbone of game engagement. By "mastery" I mean developing the knowledge to overcome a challenge, and by "agency" I mean making meaningful and consequential choices. *Fiero*—an intense emotional high from triumph over adversity (McGonigal 2011, p. 33)—is the most intense form of mastery. The model includes a third internal motivator, *growth* in one's sense of personal identity.

Knowledge Model

Games take a much more nuanced view of knowledge than "information and skills to be learned," as Gee has revealed through careful analysis of specific games (2005; 2007a; 2007b; 2010). *Information*, *skills*, *tools*, and *experiences* form the base level of knowledge. *Information* represents declarative knowledge about the game world. *Skills* represent procedural knowledge: the ability to execute actions within the world. We include *tools* within base knowledge because, from the point of view of distributed cognition, the knowledge built into a tool counts as part of the player's knowledge if she knows how to leverage the tool: "The real thinking and acting unit becomes '[player] plus tool'" (Gee 2007b, p. 187). Finally, it includes *experiences* because our collection of experiences helps us recognize where, when, and how to apply our other knowledge elements, and because humans tend to "think through experiences that they have had and imaginative reconstructions of experience" (Gee 2007a, p. 42).

Through the trial-and-error learning cycle, players develop and organize knowledge to support *strategies*. "In good games, players learn and practice skill packages as part and parcel of accomplishing things they need and want to accomplish. They see the skills first and foremost as a strategy for accomplishing a goal and only secondarily as a set of discrete skills" (Gee 2007a, pp. 40-41). Gee also observes that "Humans store their experiences best in terms of goals and how these goals did or did not work out" (2010, p. 44). This suggests the *principle of utility*: "The game should teach skills and other knowledge as parts of strategies for accomplishing specific goals."

Gee, summarizing cognitive science research, says that "Humans think and understand best when they can imagine (simulate) an experience in such a way that the simulation prepares them for actions they need and want to take in order to accomplish their goal" (2007a, p. 24). He claims that "If you can't run any models in your head… you can't really understand what you are reading, hearing, or seeing. That's how humans are built" (2007a, p. 43). To "run models in your head" implies that you must have models to run, which means that a vitally important part of learning is integrating your skills, information, tools, and experiences into functional, predictive *models*.

Gee also argues that "Domains of knowledge… are special ways of seeing, valuing, and being in the world. Physicists *do* physics. They *talk* physics. And when they are being physicists, they *see* and *value* the world in a different way than do non-physicists" (2005, p. 1). When playing a video game, "Players must carefully consider the design of the world and consider how it will or will not facilitate specific actions they want to take to accomplish their goals… The player must learn to *see* the game world… in terms of such affordances" (2007a, p. 25). Learning to succeed at a video game or profession is largely about learning the *ways of seeing* successful in that domain.

Identity Model

"Identity" is a broad and complex concept; my model will focus on only those sub-elements most directly relevant to playing and learning in video games. Gee refers to "identity" as a "way of being in the world," and identifies *goals* and *norms* as the key elements of an identity. "In a game… I am who I am… because I have certain sorts of goals and follow certain norms and values that cause me to see the world, respond to the world, and act on the world in a certain way" (2010, p. 48). In the model *goals*, *norms*, and *ways of seeing* are the three sub-elements of *identity*. The model diagram overlaps *goals* and *norms* in order to represent the fact that "norms and goals are closely related in that the norms guide how we act on our goals and assess those attempts" (Gee 2010, p. 48). "In some games… the norms amount, in part, also to a value system, even a moral system… Without such norms one does not know how to act and how to evaluate the results of one's actions as good or bad, acceptable or not" (p. 48). Norms thus help define and constrain our goals as well as influencing how we pursue them.

The Play

"The play" is the domain of co-construction between the mechanics and player. Of its four coarse-grained elements, the *proxy*, *problem*, *attempt*, and *outcome*, only the *problem* and *attempt* contain sub-elements.

Each *problem*, puzzle, challenge or other obstacle that drives game play is defined by one or more immediate *objectives*, in conjunction with the *obstacles* that prevent easy achievement of the objectives and the *affordances* that can be used for success. Gee defines an affordance as "a feature of the world (real or virtual) that will allow for a certain action to be taken, but only if it is matched by an ability in an actor who has the wherewithal to carry out such an action" (2007a, p. 25). He claims that "Playing *World of Warcraft*, or any other video game, is all about such affordances… Players must think in terms of 'What are the features of this world that enable the actions I am capable of carrying out and that I want to carry out in order to achieve my goals?'" (p.25).

The *attempt* is the portion of the model representing the player's direct activities in the game world. In an attempt, the player and character's in-game *abilities* are exercised in some *action* that may or may not lead to the desired outcomes. Minding Gee's argument that "The mind is a simulator… that builds simulations to purposely prepare for specific actions and to achieve specific goals" (2007a, p. 24), the model includes *anticipation* as an element of the attempt: envisioning the likely outcomes of various possible actions, based on the player's models of the game and its elements, so as to choose the one most likely to achieve her objectives.

Dynamical Loops

The coarse- and fine-grained elements so far presented constitute the model's structure. Its dynamics are contained in the ways these elements interact to produce the phenomenon of a game functioning as a learning system. We make the core dynamics of the model explicit by identifying four *dynamical loops*: the *intrinsic motivation loop*, the *exploratory learning loop*, the *identity growth loop*, and the *game response loop*.

Exploratory Learning Loop

The very essence of game-based learning, and thus the most critical dynamic to capture, is trial-and-error exploration. Devlin describes the player's perspective as "I can figure it out" by exploring the space and intuiting the rules (2011, pp. 77-8). Gee asserts that "Learning [in good video games] is a cycle of probing the world (doing something); reflecting in and on this action and, on this basis, forming a hypothesis; reprobing the world to test this hypothesis; and then accepting or rethinking the hypothesis" (2007b, p. 105). Therefore, at the heart of the model sits the *exploratory learning loop* (Figure 2), representing the player's struggle with and eventual triumph over each problem. During feedback-based learning, the player develops skills through practice and experimentation; accumulates new experiences; discovers new information; acquires new tools; constructs, tests, and refines models; formulates, tests, and refines strategies; and learns ways of seeing that support success in the game world. As a result, she becomes increasingly attuned to the affordances she

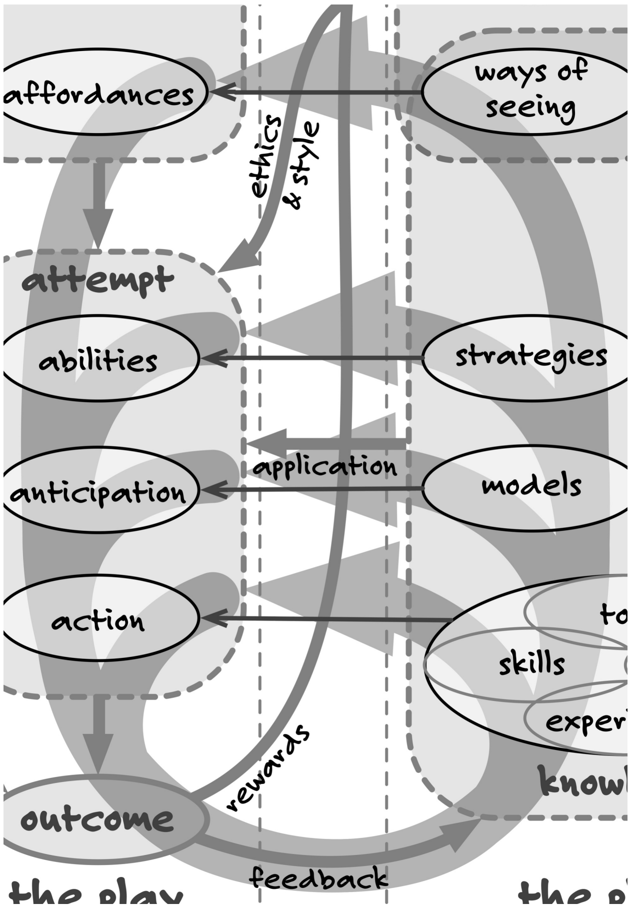

Fig. 2 The model's *exploratory learning loop*.

must leverage; grows her in-game abilities; becomes more accurate at anticipating the outcomes of possible actions; and more reliably executes the actions she intends.

The existence and centrality of this loop leads to several important implied principles. One is the *principle of safety*: "Failure should be relatively safe and non-threatening, so that a player can fail repeatedly at a challenge as she develops the knowledge and skills to succeed." Gee says, "Learners can take risks in a space where real-world consequences are lowered" (2007b, p. 64); Devlin says, "Failure doesn't hurt" (2011, p. 76). A second is the *principle of feedback*: "The game should provide players with immediate, informative feedback—ideally arising as a natural consequence of their actions—that helps them diagnose their failures, hone their skills, and fill knowledge gaps." Says Gee, "People learn best from their experiences when they get immediate feedback during those experiences so they can recognize and assess their errors and see where their expectations have failed" (2010, p. 44). A third is the *principle of visibility*: "Productive courses of action should be visible or adequately discoverable," so that the player can perceive effective possibilities without inefficient stumbling about and undue frustration.

Gee notes that in good games, "The learner is given explicit information both on demand and just in time, when the learner needs it or just at the point where the information can best be understood and used in practice," and "Overt telling is kept to a well-thought-out minimum, allowing ample opportunity for the learner to experiment and make discoveries" (2007b, p. 142). These suggest the *principle of need-driven learning*: "Exposition or other direct instruction should be minimal, integrated into game play, and offered within the context of a relevant problem." Many games make an explicit problem out of discovering, accessing, and piecing together instructional information.

Finally, the game's succession of challenges must be designed to help players efficiently discover, explore, practice, master, and extend the skills and knowledge necessary to succeed. The *principle of learning progressions* states, "The game should sequence and pace problems to help players most efficiently develop their game knowledge and skills." Gee finds that many games achieve this through "cycles of expertise" involving:

> practicing skills until they are nearly automatic, then having those skills fail in ways that cause the learners to have to think again and learn anew. Then they practice this new skill set to an automatic level of mastery only to see it, too, eventually be challenged. (2007a, p. 37)

He says, "This is the whole point of levels and bosses" (p. 37), and points out that "The problems learners face early on are crucial and should be well-designed to lead them to hypotheses that work well, not just on these problems, but as aspects of the solutions of later, harder problems, as well" (p. 35).

Identity Growth Loop

Along with growth in a player's knowledge, good games can promote expansion of a player's sense of identity. Gee says, "Learning involves taking on and playing with identities in such a way that the learner has real choices (in developing a virtual identity) and ample opportunity to meditate on the relationship between new identities and old ones" (2007b, p. 64). He also says, "Real learning is often linked to ideology. Adopting a certain set of values and a particular world view is intimately connected to performing the activities and having the experiences that constitute any specific domain of knowledge" (2005, p. 3), "including learning content actively and critically in school" (2007b, p. 55). Squire finds that "Players develop new identities both through game play and through the gaming communities in which these identities are enacted… Games can communicate powerful ideas and open new identity trajectories for learners" (2006, p. 19). He notes that identity can be a driver as well as an outcome of learning: "Learning [in certain games] is… doing, experimenting, discovering for the purposes of action in the world. Players learn in role-playing games for the purposes of acting within an identity" (Squire 2006, Table 1). The model incorporates this dynamic through the *identity growth* loop (Figure 3) that represents iterative development of an identity through exploratory game play and learning.

Intrinsic Motivation Loop

A game fails if the player does not continue to voluntarily engage in its problems; a successful game must

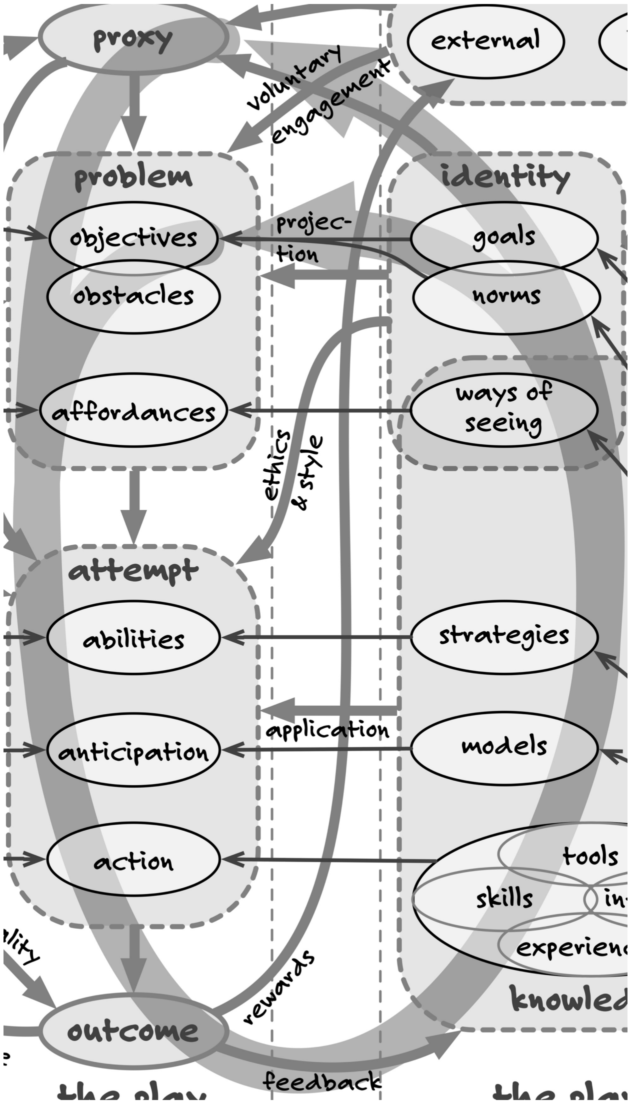

Fig. 3 The model's *identity growth loop*.

stimulate intrinsic motivation. The model's *intrinsic motivation loop* (Figure 4) captures the three main pathways through which this happens. The first is by giving players a sense of *mastery & agency* as they struggle with and overcome challenges, expanding their capacities in the process (i.e., learning). The second is by giving players a sense of *growth* as they explore new identities and/or expand their existing one(s). The third is by providing inherently entertaining and enjoyable *rewards* through the direct experience of game play, such as aesthetically pleasing or spectacular audiovisual effects; a dramatic or humorous storyline; unexpected surprises and humor; discovery; high-adrenaline thrills; and, with new kinds of game controllers, even physical movement. Most good games deftly employ all three pathways to grab and hold players' interest, which is why they are often called "addictive."

Game Response Loop

For game play to be a co-construction of the player and game, the game must react to the player's actions. A game can tune the difficulty of its challenges; adjust the sequence of problems it presents; let player actions alter or reshape the game space and create, change, or destroy game elements; modify the virtual capacities it provides; modify the interface it presents; and alter the fundamental physics of the game. It can also change or expand the set of representations it uses to communicate these things to the player. The model represents this as a *game response loop* (Figure 5) cycling through the problem, player attempts, and outcome back through the game world elements, problem sequence, and win state. Via this loop, a player's choices and successes reshape the game environment and rules, determine the next problems encountered, and even alter the player's overall objectives. One critical function of this loop is to tune challenges to the player's level of competence, finding the optimal balance between frustration and boredom. Another is to foster the player's sense of agency, allowing her actions to have consequences—perhaps epic ones—for the game world. A third is to support different styles and strategies of play.

Human-Computer Melds

Earlier, we noted that a game is a co-construction of the programmed game mechanics and the player. One obvious aspect of this is that the sequence of events and their outcomes—the game's plot—depend on how the player

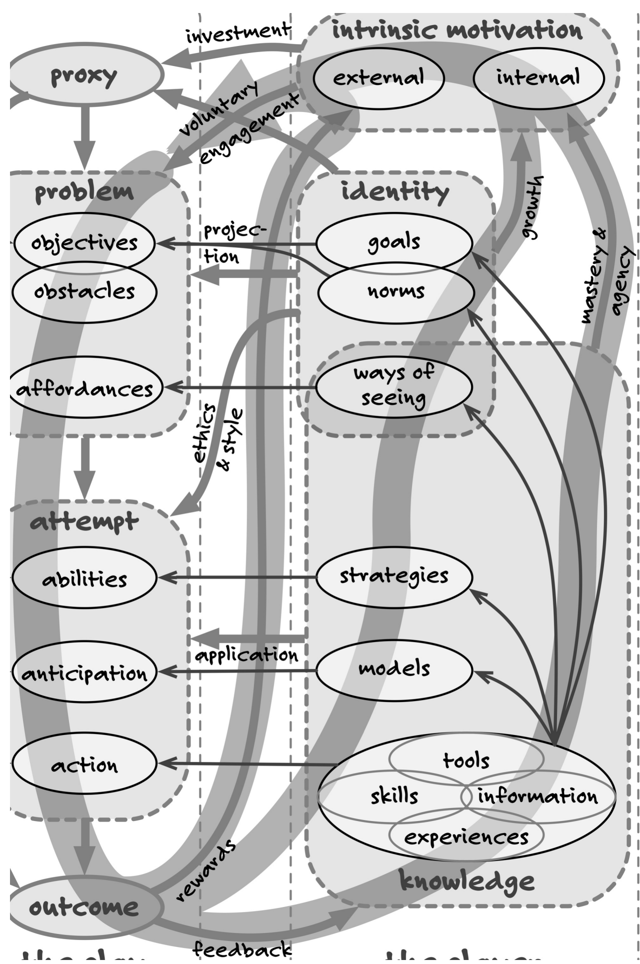

Fig. 4 The model's *intrinsic motivation loop*.

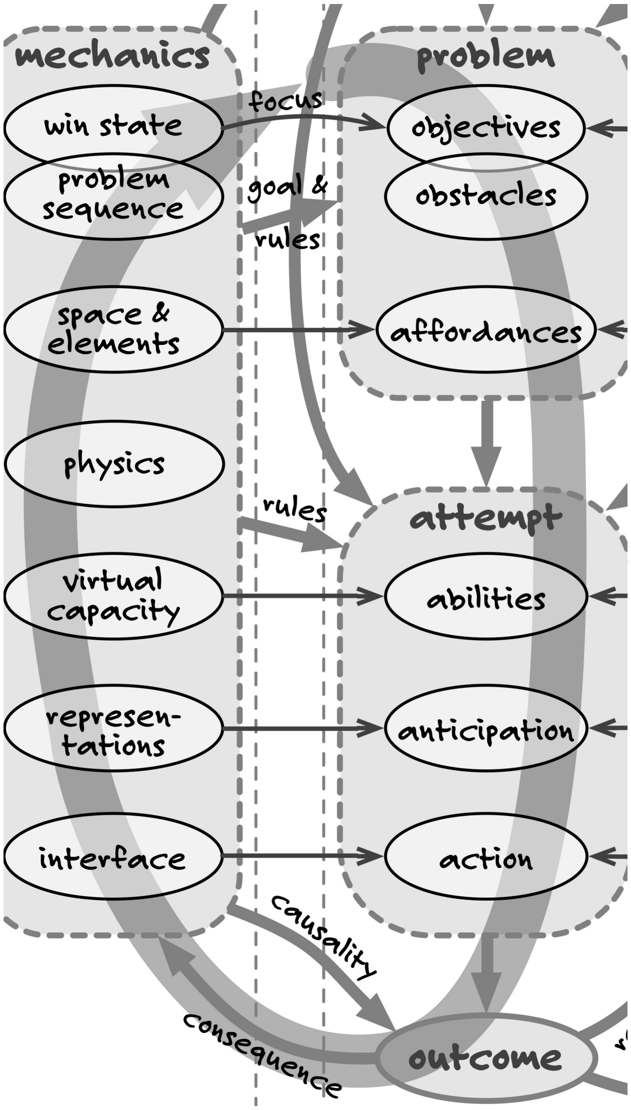

Fig. 5 The model's *game response loop*.

interacts with the game. A less obvious, but no less important, aspect is that the games' challenges are not overcome by the player herself, but by the player acting through her proxy. The player becomes part of a hybrid human-plus-computer entity operating within the game's virtual world. Scattered across his various writings, Gee has identified five different ways in which good games support such an extension of a player's sense of self. I call these *human-computer melds*, and they constitute another dimension of the model's dynamics. Like the dynamical loops, they represent ways that the model elements interact to engender engagement and learning. Whereas the loops resent chronological sequences, however, the melds represent simultaneous coordination of elements across the model's three spaces: the game, the play, and the player. Figure 6 represents these five melds.

Projective Identity

Gee identifies three different identities involved in the play of a game (2007b, p. 48ff). One is the virtual identity of the in-game character that the player controls. Whether a disembodied perspective or a person-like avatar, this proxy is imputed to have specific objectives and values, and accomplishing or satisfying these constitutes "winning." A second is the real-life identity of the player engaging in the game. She has her own goals and standards for playing, which might include obtaining a high score, exploring new regions of the game world, impressing friends, or procrastinating on physics homework. A third is a "projective identity," so named because the player projects herself into her character, and also because the character becomes an ongoing project-in-the-making of the player. The player's "projective goals" for the character might include demonstrating a particular personality, achieving an in-game distinction, or living up to standards beyond those prescribed by the game.

The model represents this dynamic with the *projective identity* meld (labeled "PI" on the figure). It signifies a complex interplay between the game's explicit win state and challenges, the character's (or abstract proxy's) formal objectives, and the player's personal goals and norms. The player's projective goals for her proxy arise as she injects elements of her identity into its objectives, altering or augmenting the *problem* that directs game-play. Note that the more leeway a player has in choosing specific objectives and achieving them in different ways, the more room the game provides for the formation of a projective identity, and therefore the more powerful this meld dynamic can be. This suggests the *principle of idiosyncrasy*: "The game should allow and encourage players to make significant choices about how they will play, freedom to win via different approaches and styles, and ways to personalize and experiment with their in-game characters."

Seeing in Affordances

The very structure of a game—its elements and the ways they can be manipulated—teaches a player to view the world in terms of the affordances it offers for achieving goals (Gee 2007a, p. 25ff). In games that emphasize skulking and hiding, players become highly attuned to light and shadow; in ones that emphasize military maneuvers, cover from enemy fire; and in ones that stress accumulating a personal arsenal of increasingly powerful tools, virtual characters who can be robbed or traded with. The game teaches players what lenses to look at the game world through. In a sense, the player is learning to inhabit her character's perceptions and see the world through its eyes. Accordingly, the model's second human-computer meld is *seeing in affordances* ("SA" on the figure). It links the player's *ways of seeing* with the game's *space and elements*, based on the *affordances* they offer for solving the problem at hand. It suggests the *principle of affordances*: "The game should provide learning pathways and resources that sensitize players to the important affordances."

Enhanced Competence

As noted earlier, most games permit the player to perform in-game actions that she is not capable of in real life. The overall abilities of the player-in-game are therefore a synergy of the proxy's game-provided virtual capacities and the knowledge-based strategies the player has developed for using those capacities. "One key feature of the

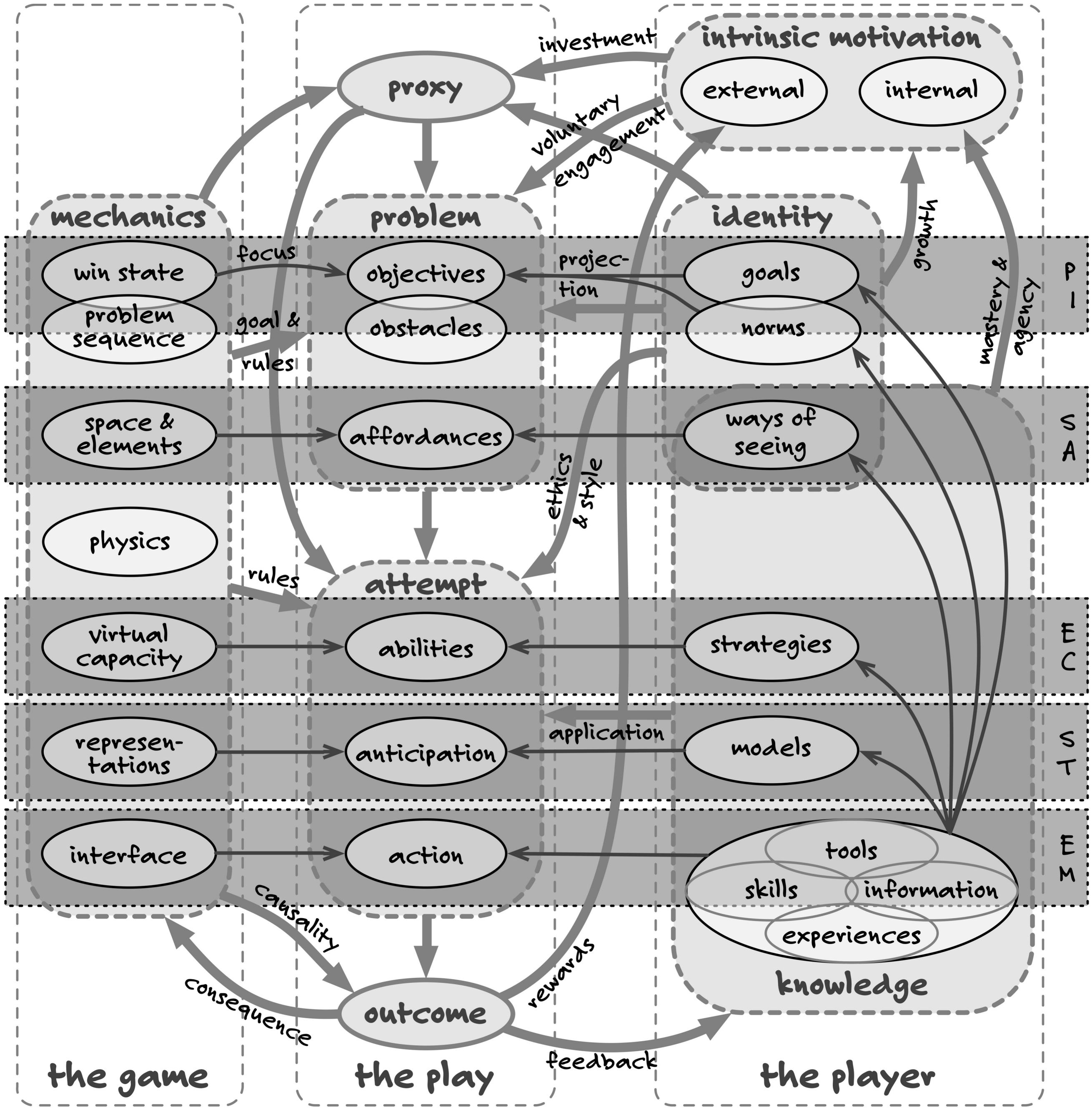

Fig. 6 The model's five human/computer melds.

virtual characters and objects that game players manipulate is that they are 'smart tools'… The player and the character each have knowledge that must be integrated to play the game successfully" (Gee 2007a, p. 33). In a simple arcade-style "platformer" like *Super Mario Brothers*, the player provides the strategic knowledge for when and where to jump and the character provides the jumping ability. In a more complex game like *Full Spectrum Warrior*, the player provides the strategic knowledge of what platoon formations to use in what circumstances, and the virtual solders under her command provide the knowledge of how to assume and move in those formations. The model represents this via the *enhanced competence* meld ("EC" on the figure). It connects both the game-provided *virtual capacities* with the player-provided *strategies* (and therefore, implicitly, with her base knowledge of information, skills, tools, and experiences) to form her actual *abilities* within the game play. This suggests the *principle of enhanced competence*: "The game should provide virtual capacities and smart tools that let players experience and enjoy in-game competencies they do not possess in reality."

A particularly strong form of enhanced competence found in some games is "distributed authentic professionalism," through which a player can experience functioning as a specific kind of professional (loosely defined) accomplishing authentic (albeit simulated) tasks (Gee 2005). This dynamic has great instructional potential: "In such games, skills, knowledge, and values are distributed between the virtual characters and the real-world player in a way that allows the player to experience first-hand how members of that profession think, behave, and solve problems" (p. 1). "By the end of the game, the player has experienced a 'career' and has a story to tell about how his or her professional expertise grew and was put to tactical and strategic uses" (p. 4). More generally, enhanced competence can allow a player to dive right into authentic (to the game world) tasks from the beginning of the game, learning by doing rather than undergoing an extended period of instruction in order to have the base knowledge to even approach "real" challenges—what Gee calls "performance before competence" (2007a, p. 27). This suggests the *principle of authenticity*: "The game should provide scaffolding that lets players learn from the beginning by engaging in behavior authentic to the identity, profession, and/or setting of the game."

Simulation Thinking

"Humans think and understand best when they can imagine (simulate) an experience in such a way that the simulation prepares them for actions that they need and want to take in order to accomplish their goals" (Gee 2007a, p. 24). Gee notes that the human mind thinks best and most naturally in terms of remembered or imagined action images, rather than abstract propositions or formalism; words and concepts obtain meaning from the experiences we link them to; and problem-solving generally involves running simulations in our minds in order to explore possible courses of action and predict their outcomes (pp. 42-3).

> Since fruitful thinking involves building simulations in our heads that prepare us for action, thinking itself is somewhat like a video game, given that video games are external simulations… [A game] allows players to experience in a visual and embodied way [certain] situations. They can then learn to build simulations of these in their heads and think about possible actions and outcomes before rushing into action. They can then act in the game, judge the consequences…, and build new, perhaps better simulations to prepare for better actions. (p. 80)

Koster agrees: "What a book will never be able to do is accelerate the grokking [deep learning] process to the degree that games do, because you cannot practice a pattern and run permutations on it with a book" (Koster 2005, p. 36). In other words, a game can help us do our simulation-based thinking by externalizing some of the simulation.

The model incorporates this dynamic with its *simulation thinking* meld ("ST" on the figure). The player builds and refines her *models* of the game world's spaces, elements, and physics in terms of the various *representations* the game provides, and runs mental simulations in terms of these representations in *anticipation* of various possible actions. The exploratory learning loop allows her to mix mental simulations and experimental gameplay as she considers possibilities and develops strategies. This dynamic suggests the *principle of representations*: "The game should provide concrete representations designed to help players develop mental models and run mental simulations of the game's most important elements, principles, and ideas." It also suggests the *principle of experimentation*: "The game should support comparative exploration of situations or courses of action."

Extended Manipulation

A video game is played in a virtual world that is necessarily simpler and more restricted than reality, and the player must operate through the constraints of a fairly limited interface. This may seem like a disadvantage, but it can be a powerful advantage. Gee says "Fine-grained action at a distance… causes humans to feel as if their bodies and minds have stretched into a new space… Humans feel expanded and empowered when they can manipulate powerful tools in intricate ways that extend their area of effectiveness" (2007a, p.33).

> When people are playing a computer or video game they are manipulating a character (or many different things in a RTS game) at a distance in a very fine-grained way—in this case a virtual distance. This process allows players to identify powerfully with the virtual character or characters they are playing in a game and to become strongly motivated to commit themselves to the virtual world the game is creating with their help. (2007a, pp.49-50)

Schell emphasizes the critical role of the game's interface in this phenomenon: "The player puts their mind inside the game world, but the game world really only exists in the mind of the player… This magical situation, which is at the heart of all we care about, is made possible by the game interface" (2008, p. 222). A good interface should "make players feel in control of their experience" (p. 222); should become "invisible to the player letting the player's imagination be completely immersed in the game world" (p. 227); should provide rapid and helpful feedback (p.230); and should be "juicy" by providing a continuous flow of reward in return for just a little bit of interaction, and by creating "second-order motion" derived from the player's actions but not directly executed by her (p. 233).

To represent this dynamic, the model's fifth and final human-computer meld is *extended manipulation* ("EM" on the figure). It links the game's *interfaces* with the player's base *knowledge* (especially skills and tools) to produce *action* in the game play, and implicitly represents the notion that while the player acts *on* the game, she should have the illusion of acting *within* the game. The *principle of manipulation* follows from this dynamic: "The game's interface should provide fluid, transparent, juicy control over game elements and rich immediate feedback, to create the illusion that players are acting within the game world."

The Multi-Layer Game

Modern video games function on multiple levels: as problem-solving challenges that teach skills (Koster 2005); as designed experiences that tell a story, embed ideology, and develop identities (Schell 2008; Squire 2006); as social phenomena that foment and structure camaraderie and collaboration (Steinkuehler & Duncan

2008); and as opportunities to design, build, and contribute to something (Gee 2007b). The model structure and dynamics we have presented so far can be applied to each of these four different levels, albeit with some reinterpretation. I call these four levels the *micro-level game*, the *macro-level game*, the *social meta-game*, and the *builder meta-game*.

The *micro-level game* represents the game as "a series of interesting challenges." Applied to this layer, the model describes the base game dynamics of overcoming a sequence of specific obstacles through trial-and-error learning. This is the most obvious, visible level of the game. At each point of play, the *problem*, *game world elements*, and *outcome* are concrete and visible, and *knowledge* supports strategies to accomplish specific actions. The player's focus is on solving the immediate problem at hand, and her proxy is merely a mechanism for manipulating game elements. "Learning" means developing facility with the interface, discovering basic game facts and secrets, figuring out when and how to execute possible actions, acquiring important tools, building mental models of how the game world's elements behave and how its spaces interconnect, and structuring base knowledge into tactics for overcoming the various types of obstacle encountered. The player's relevant identity is that of a gamer playing the game. The primary external intrinsic motivators (rewards) are perceptual, based on the sights, sounds, and events of gameplay—what Schell calls *juiciness* (2008, p. 233). The primary internal motivator is the feeling of *mastery* born of overcoming challenges. Recognizing the importance of this layer of the game, we present the *principle of puzzles*: "The game's individual puzzles should be inherently interesting."

The *macro-level game* represents the game as "a designed experience," re-interpreting the model to describe the higher-level, holistic experience that emerges out of micro-level game play. This layer addresses the fictional world, the storyline, and the player's virtual/projective identity. The player's proxy is her in-game character, complete with goals, values, and fictional history. The problem represents a scenario to be played out, pursuing scenario-level goals through conflict with enemies or other opposing forces, leading to an outcome which is a plot development. The game's elements are settings, story characters, historical events, and other significant pieces of the plot. The knowledge a player accrues includes models of the game world and forces at work within it, along with stratagems for influencing them. It also includes the ability to function as a certain kind of individual within the game world, which means developing an alternate identity as a competent "professional" (broadly defined), internalizing its goals, norms, and ways of seeing. Identity growth and agency are powerful internal motivators, as the player finds herself at the center of an unfolding story and makes choices that define her character and shape the plot. The satisfaction of "grokking" (deeply understanding) a complex game world also provides internal motivation. The game's primary external motivator (reward) is the entertainment value of an intriguing world and a compelling story. At this level, the player's focus is on the overall experience she is having of the world and of her identity within the world, and "learning" means developing "new ways of thinking, knowing, and being in worlds" (Squire 2006, p. 25) through "a grammar of *doing* and *being*" (p. 19). The *principle of designed experience* acknowledges the importance of this layer: "The game should present a coherent, interesting setting, theme, and storyline, of which the challenges of the micro-level game form an integral part."

The *social meta-game* represents the "affinity space" of people interacting with each other in, through, and about the game. *Affinity space* is a complex concept (Gee 2007a Ch.8); loosely speaking, it means a set of interconnected real or virtual spaces, informally organized, in which diverse people interact about and around a topic of mutual interest. The affinity space for a typical modern video game might be comprised of the game world itself; locations where players congregate to play; official and unofficial web sites about the game; social media channels; and collections of player-contributed strategy guides, "walkthrough" videos, extensions and "mods" (modifications), and fan fiction. The space is likely frequented by expert players, novice players, fans of the game's fictional world, and employees of the game design company.

To adapt the model template to the social meta-game, we replace the game *mechanics* by the social technologies that create and mediate interactions within the affinity space and the (generally digital) artifacts they contain. The player's *proxy* is the persona(s) she adopts within the space. Instead of a *problem*, activity focuses on collective actions such as assisting newcomers, documenting the game world, sharing discoveries and victories, enjoying the fictional setting, and jockeying for social status. *Attempts* are social moves or gambits executed with some expected outcomes, successful or not depending on the player's social skills, models of the social world and its inhabitants, and resources. The *outcome* is some specific interaction between meta-game participants. At this level, the player's focus is on the social experience she is having interacting with others about and around the game. "Learning" means both developing increasingly sophisticated social models and interaction strategies, and growing her social identity as a community member. As Squire has found, "Players develop new identities both through game play and through the gaming communities in which these identities are enacted" (2006, p. 19). The *principle of social interaction* advises that "Game designers should foment social interaction within and around the game through the design of the game itself and the provision of associated services and initiatives."

The *builder meta-game* represents the possibilities available for players to contribute to the collection of artifacts and technology constituting the game and its ecosystem (including the affinity space of the social meta-game layer). Many games include "modding" (modification) tools that allow players to alter game mechanics or design additional game spaces and challenges. Some games have spawned large collections of fan fiction and art. At this level, the relevant *mechanics* are the ecosystem of the game and its attendant technologies, including architectural features that invite certain kinds of contributions, tools for modding or extending the game, channels through which player contributions can be shared, and the history of the game ecosystem and its community. The player represents herself as a designer, taking on a potential contribution as her *problem*. She combines the game ecosystem's tools with her *knowledge* to undertake a project whose *outcome*, hopefully, is a product. Within this layer, the player takes on the *identity* of a producer or maker

> Good video games allow players to be not just passive consumers but also active producers who can customize their own learning experiences. The game designer is not an insider and the player an outsider, as in school in so many instances… Rather, game designers and game players are both insiders and producers—if players so choose—and there need be no outsiders. (Gee 2007b, pp. 208-9)

Primary external motivators are the status that arises from contributing a valued product to the ecosystem (thus interconnecting the *builder* and *social meta-games*), and enjoyment of one's creations. The primary internal motivator is pride in one's accomplishments and growing craft skills. The player's focus is on her design process: a sequence problem-solving episodes, as in the micro-level game, but of her own choosing, in pursuit of her own agenda. "Learning" means developing the craft knowledge necessary to accomplish her goals, and can take the player far beyond the "content" of the game itself. To help this happen, we suggest the *principle of building*: "Game designers should provide tools that enable players to alter, extend, and otherwise contribute to the game and its ecosystem."

Summary and Discussion

In this article, I have presented a model of "games as learning systems" that integrates observations and ideas drawn from a range of literature on games and their instructional properties. In so doing, I have attempted to identify the most important elements or aspects of the game mechanics, the player, and the co-constructed play. I have identified dynamical processes critical to the functioning of games, representing them as four dynamical loops and five human/computer melds. I have also indicated how the model can be applied at four different levels to capture the fact that game play is often a multi-layered phenomenon. Before discussing applications, I will comment briefly on two aspects of game-based learning that the model does not address.

Effectiveness: The model describes elements and dynamics that many games have, and that good games use well. The mere presence of these elements and dynamics do not necessarily make a game effective for learning or entertainment. Determining the qualities that make a combination of game elements succeed or fail is a worthwhile agenda for empirical research. The model should provide a productive framework for conducting this research, as well as for diagnosing flaws that might prevent game-like educational experiences from succeeding.

Implementation mechanisms: The model does not indicate specifically how these various elements, dynamics, and principles can be instantiated in a particular game. Analysis of extant games reveals many different architectural design patterns, strategies, and techniques that game designers commonly employ. Some are obvious, such as the use of *levels and leveling up* to indicate and pace progress; *minions and level bosses* to foster focused skill learning and demonstration of mastery; *evolving character profiles* to connect identity to game progress; *character customization* to support idiosyncrasy and invest players in their game characters; *narrative text and cut-scenes* to integrate puzzles and challenges into a larger storyline; and *Easter eggs* to provide surprise and incentivize thorough exploration. Others are more subtle or sophisticated. Gee has articulated several, including *smart tools* that automate basic tasks so players can focus on higher-level skills; *fishbowls* and *sandboxes* to help novices learn while playing; and *cross-functional affiliation* to recruit social motivation, support specialization, encourage externalization of knowledge, and enable harder challenges (2007a; 2007b). To support game-based and game-informed instruction, I see great value in developing an inventory of game architectures, design patterns, and implementation strategies, linked to the specific model elements, dynamics, and principles that they instantiate or facilitate.

Applying the Model Analytically

Using the model to conduct a detailed analysis of extant games, curricula, pedagogies, or other learning systems is beyond the scope of this article. However, a brief indication of its applicability is warranted. As an example, we will view the *Modeling Instruction* approach to teaching physics through the lens of the model.

Modeling Instruction (MI) is a pedagogy and curriculum for teaching high school physics (Halloun 2007; Hestenes 1987; 1992), later adapted to university-level physics (Brewe 2008). Both versions are highly successful. MI has been formally taught to approximately 10% of US high school physics teachers (Brewe 2008), and has produced the first positive attitudinal shifts ever reported for an introductory physics course on the *Colorado Learning Attitudes about Science Survey* (Brewe, Kramer, & O'Brien 2009). MI organizes course content around a small number of general "models" that integrate concepts, definitions, laws, and representational tools, and consistently follows a pedagogical progression in which students are steered to develop, test, and refine these models (in groups and as a class) through hands-on inquiry and collaborative sense-making.

According to my model, the core dynamic of game-style learning is solving a sequence of problems through trial-and-error exploration. The "modeling cycle" followed by MI fits this well, with "a development cycle that is continually employed in the progression from qualitative to quantitative models and on to model testing and refinement" (Brewe 2008). "Inquiry laboratories and activities focused on conceptual reasoning and problem solving are the primary vehicles through which models are built, validated, and extended" (Brewe et al. 2009, p. 2). The model-forming process necessarily involves exploration, failure, and revision. Students get rapid natural feedback by comparing their models' predictions to observed data and by subjecting their ideas to rigorous discussion and debate with their peers. In contrast to this, traditional physics instruction typically exposes students to new content didactically, through lecture or reading; then presents problems for them to solve as practice; and, days later, returns feedback in the form of graded homework and exams.

MI also incorporates the identity growth loop. Because students are explicitly engaged in the process of doing science rather than merely learning about it, and follow many of the epistemological practices of physicists, they can develop identities as scientists and physicists. "The implementation of Modeling Instruction at FIU is designed to give students an authentic scientific experience and to make the nature of science a coherent theme across content and pedagogy" (Brewe et al. 2009, p. 2).

Applying the Model Generatively

The model can also be used generatively, as a provocation that challenges us to improve our science instruction in various specific ways, a source of ideas for changes to try, and a tool for thinking outside the historical and cultural "box" of implicit assumptions we bring to education. One approach is to select a component or aspect of the model and consider ways of instantiating it in classroom-based science instruction. For example, the importance of the *exploratory learning loop* prompts us to ask, "How can we structure a science course as a sequence of puzzles or problems, such that students can explore and experiment with each until they learn what they need, with expository support provided minimally and on-demand or just-in-time? How can we represent the landscape of content ideas, tools, and challenges visibly and accessibly so that students can learn via exploration? How can we structure it so that such exploration is fruitful?" The fact that game-learned knowledge is organized into *strategies* for accomplishing desired goals prompts us to ask, "What strategies justify the content knowledge being taught, what goals motivate those strategies, and how can we foreground the strategies rather than the elemental skills and information?" The *enhanced capacity* human/computer meld prompts us to ask, "How can we provide smart tools and virtual capacities that enhance students' capabilities in the subject area so that they can attend to higher-level considerations and have a more authentic experience of functioning as a professional?"

Similarly, awareness of the *macro-game layer* prompts us to ask, "How can we envision the course as a designed experience rather than as content to teach? What is the setting, what story lines unfold, and what identities can students develop?" Focusing on the *identity growth loop* prompts us to ask, "How can we frame a science course as deliberately exploring a new professional identity?" Focusing on the meta-game layers prompts us to ask, "How can we enable students to contribute to an ecosystem and participate in an affinity space, rather than being reactive consumers of a predesigned curriculum?" Mindful of the *principle of agency*, we ask, "How can we give students' choices consequence for the world of the classroom and its unfolding history?"

Concluding Comments

A model is neither correct nor incorrect; it is merely more or less useful. The model laid out above will be justified by the degree to which others find it helpful to support thinking, discourse, analysis, and design. My hope is that it will enable education researchers and instructional designers to think about science teaching in qualitatively new ways, using video games as a lens and inspiration.

My most significant concern is that our current structures and assumptions about schooling, and the ways we conceptualize our academic disciplines, are antithetical to game-based learning dynamics—not out of necessity, but from history, habit, and inertia. For example, much about games arises from the fact that they are self-paced and voluntary. This is the root of player agency. In school, however, we require students to complete courses in one academic term. Many courses are mandated by major or general education requirements. After a specified date, students cannot withdraw from a course without academic penalty. What space, then, is left for *voluntary participation*?

If we really look to good video games as models of effective learning design, and follow the implications, we may have to challenge almost everything about the ways that we currently understand and do "school."

References

Barsalou, L. W. (2009). Language comprehension: Archival memory or preparation for situated action? *Discourse Proceses*, *28*(1), 61–80.

Begg, M., Dewhurst, D., & Macleod, H. (2008). Game-informed learning: Applying computer game processes to higher education. *Innovate*, *1*(6), 1–7.

Bogost, I. (2007). *Persuasive Games*. The MIT Press.

Brewe, E. T. (2008). Modeling theory applied: Modeling Instruction in introductory physics. *Am J Phys*, *76*(12), 1155.

Brewe, E. T., Kramer, L. H., & O'Brien, G. E. (2009). Modeling instruction: Positive attitudinal shifts in introductory physics measured with CLASS. *Phys Rev Spec Top-PH*, *5*(1).

Chabay, R., & Sherwood, B. (2008). Computational physics in the introductory calculus-based course. *Am J Phys*, *76*(4), 307.

Devlin, K. (2011). *Mathematics Education for a New Era*. A. K. Peters Ltd.

Gee, J. P. (2005). What would a state of the art instructional video game look like? *Innovate*, *1*(6), 1–6.

Gee, J. P. (2007a). *Good video games + good learning*. Peter Lang Publishing.

Gee, J. P. (2007b). *What video games have to teach us about learning and literacy* (2nd ed.). Palgrave MacMillan.

Gee, J. P. (2010). Video Games, Learning, and "Context." In C. T. Miller (Ed.), *Games: Purpose and Potential in Education* (pp. 43–53). Springer.

Gorton, W., & Havercroft, J. (2012). Using Historical

Simulations to Teach Political Theory. *J Polit Sci Educ*, *8*(1), 50–68.

Halloun, I. A. (2007). *Modeling Theory in Science Education*. Springer.

Hestenes, D. (1987). Toward a modeling theory of physics instruction. *Am J Phys*, *55*(5), 440–454.

Hestenes, D. (1992). Modeling games in the Newtonian world. *Am J Phys*, *60*(8), 732–748.

Honey, M. A., & Hilton, M. L. (Eds.). (2011). *Learning Science Through Computer Games and Simulations*. The National Academies Press.

Jackson, J. (2009). Game-based teaching: what educators can learn from videogames. *Teach Educ*, *20*(3), 291–304.

Koster, R. (2005). *A Theory of Fun for Game Design*. Paraglyph Press.

Malone, T. W. (1980a). *What makes things fun to learn? A study of intrinsically motivating computer games*. Xerox Palo Alto Research Center. http://cci.mit.edu/malone/tm%20study%20144.html. Accessed 7 June 2014.

Malone, T. W. (1980b). What makes things fun to learn? Heuristics for designing instructional computer games (pp. 162–169). *Proceedings of the 3rd ACM SIGSMALL symposium on Small systems*, ACM.

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

McGonigal, J. (2011). *Reality Is Broken: Why Games Make Us Better and How They Can Change the World*. Penguin Group US.

Nunes, T., Schliemann, A., & Carraher, D. (1993). *Street Mathematics and School Mathematics*. Cambridge University Press.

Schell, J. (2008). *The Art of Game Design: A Book of Lenses*. Elsevier.

Sheldon, L. (2011). *The Multiplayer Classroom: Designing Coursework As a Game*. Cengage Learning.

Squire, K. D. (2003). Video games in education. *Int J Intell Games & Simulation*, 49–62.

Squire, K. D. (2006). From Content to Context: Videogames as Designed Experience, *35*(8), 19–29.

Squire, K. D. (2008). Open-ended video games: A model for developing learning for the interactive age. In K. Salen (Ed.), *The Ecology of Games: Connecting Youth, Games, and Learning* (pp. 167–198). The MIT Press.

Squire, K. D., & Jan, M. (2007). Mad City Mystery: Developing Scientific Argumentation Skills with a Place-based Augmented Reality Game on Handheld Computers. *J Sci Educ Technol*, *16*(1), 5–29.

Steinkuehler, C. A., & Chmiel, M. (2006). Fostering scientific habits of mind in the context of online play (pp. 723–729). *Proceedings of the 7th international conference on Learning sciences*, International Society of the Learning Sciences.

Steinkuehler, C. A., & Duncan, S. (2008). Scientific Habits of Mind in Virtual Worlds. *J Sci Educ Technol*, *17*(6), 530–543.