2011

Effective Knowledge Development in Game-Based Learning Environments: Considering Research in Cognitive Processes and Simulation Design

Amy B. Adcock
Old Dominion University

Ginger S. Watson
Old Dominion University, gswatson@odu.edu

Gary R. Morrison
Old Dominion University

Lee A. Belfore
Old Dominion University, lbelfore@odu.edu

Original Publication Citation
Adcock, A. B., Watson, G. S., Morrison, G. R., & Belfore, L. A. (2011). Effective knowledge development in game-based learning environments: Considering research in cognitive processes and simulation design. In Information Resources Management Association (Ed.), *Gaming and Simulations: Concepts: Methodologies, Tools and Applications* (pp. 409-425). IGI Global. https://doi.org/10.4018/978-1-60960-195-9.ch206

Chapter 2.6

Effective Knowledge Development in Game-Based Learning Environments:
Considering Research in Cognitive Processes and Simulation Design

Amy B. Adcock
Old Dominion University, USA

Ginger S. Watson
Old Dominion University, USA

Gary R. Morrison
Old Dominion University, USA

Lee A. Belfore
Old Dominion University, USA

ABSTRACT

Serious games are, at their core, exploratory learning environments designed around the pedagogy and constraints associated with specific knowledge domains. This focus on instructional content is what separates games designed for entertainment from games designed to educate. As instructional designers and educators, the authors want serious game play to provide learners with a deep understanding of the domain, allowing them to use their knowledge in practice to think through multifaceted problems quickly and efficiently. Attention to the design of serious game affordances is essential to facilitating the development of domain knowledge during game play. As such, the authors contend that serious game designers should take advantage of existing prescriptions found in research on knowledge development in exploratory learning environments and tests of adaptive instructional designs in these environments. It is with this intention that the authors use evidence from research in cognitive processes and simulation design to propose design heuristics for serious game affordances to optimize knowledge development in games.

DOI: 10.4018/978-1-60960-195-9.ch206

INTRODUCTION

Zyda (2005) defines serious games as "a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy and strategic communication objectives" (p. 26). Serious games present players with a contextualized problem, rules (guided by constraints associated with the content), multiple interacting elements, and cognitive tools that allow users to freely discover solution paths in the tradition of exploratory, problem-based learning. In a way, serious games can be thought of as a sense-making activity; players are constrained by the rules associated with their domains (situated context) but otherwise use the affordances in the game to make sense of domain-related concepts needed to complete game objectives. For example, to represent the fact that mixing acids and bases will cause an explosion, it is necessary to generate a rule to restrict actions in a chemistry game.

Unlike training simulations, which are held to realistic representations and high levels of detail at all levels, serious games are able to place players in fantastic situations where they are asked to take on specific roles and where representations might be simplified to focus on target knowledge (Crawford, 1984). While in the game world, players observe the consequences of their decisions and are constantly challenged to fill knowledge gaps through problem solutions that require retrieval of prior knowledge (Van Eck, 2007). As they work to fill these knowledge gaps, players integrate domain knowledge into their cognitive systems, thus gaining knowledge of the domain (Foster & Mishra, 2009).

Serious game environments are inherently complex, as there are many elements working in harmony to create the game experience. Potential for collaboration, cross disciplinary activities and situated learning are all possible in a well-designed serious game. Gee (2004) suggests designers focus on designing games to keep learners hooked (even when dealing with complex information). He suggests approaches like well-defined problem statements and practice in context to sustain the players' interest throughout the life of the game. Certain properties such as motivation (Low, this volume), flow (Reese, this volume), and adaptability (Magerko, Heeter & Medler, this volume) are also essential to creating an environment where learners want to play and are motivated to come back and replay.

Designers of serious games can take advantage of the freedom to simplify representations, insert features such as custom avatars, transition scenes, inventories, maps, and non-player characters and focus on necessary domain knowledge by carefully crafting problems, rules and cognitive tools: what we refer to as serious game affordances. To design a serious game that is not only entertaining but also educational, these affordances should be designed with careful attention to the cognitive development of the players; we feel these considerations are critical to the serious game design process. The purpose of this chapter is to provide heuristics for the design of serious game affordances to support the learner as they develop their domain understanding.

To construct these heuristics, we will examine research in cognitive processes related to knowledge development from within the framework of the development of expertise. We begin with a review of the literature on development of expertise to provide evidence of the most efficient means of supporting a learner as they move from domain novice to expert thinker and beyond. We use these findings to address a critical issue in serious game design: the development of a player-driven exploratory learning environment that supports the development of domain-related schema through verified supports and affordances. To facilitate optimal serious game design, we propose a set of design heuristics specifically aimed at supporting knowledge development for meaningful learning outcomes.

SUPPORTING THE KNOWLEDGE CONTINUUM

The Process of Knowledge Development

Human memory systems consist of a sensory, short-term (working) and long-term memory stores (Atkinson & Shiffrin, 1968; Baddeley, 1992). Theories of knowledge development account for the strengths and limitation of each memory type and the processing that occurs when information moves from short- to long-term memory (encoding) and back for later use (retrieval). Optimal learning environments are designed to facilitate the encoding of information through the design of affordances to support every knowledge level of the learner, allowing for either rehearsal or practice with increasingly complex problems. Ideally, it is this process that helps novice learners develop into seasoned domain experts who can transfer knowledge from instructional environments to practice, solve divergent problems, and present creative solutions. It is the organization and storage of information chunks into long-term memory schemas that truly allows for a flexible approach to situated problems even over long periods of time (Mayer, 2009).

Stages of Knowledge Acquisition: The Knowledge Continuum

Domain expertise can be quantified in several different ways (e.g. ability to solve complex problems, level of automaticity when recalling prior knowledge). Anderson (2000) presents three stages of skill acquisition leading to the development of a domain expert. In the cognitive (novice) stage, learners begin to understand the processes or concepts related to the domain through the acquisition of declarative or foundational knowledge. Learners at this stage require a high level of detailed information about the domain area and any necessary supports for understanding or visualizing. In the associative (experienced) stage, connections are made linking individual knowledge units together into procedural knowledge. At this point, the level of detail is reduced, as the learner is able to create larger chunks of information. Learners can begin working autonomously as long as proper scaffolding is provided. In the final level of knowledge development, the autonomous (expert) stage, connections among essential domain knowledge are internalized and learners can make automatic associations. Supports can be gradually faded as learners are able to perform tasks without the support an expert model. It is in this stage that learners are able to think conditionally, divergently and transfer knowledge from one problem set to an isomorphic problem.

This sequence of knowledge development can be visualized as the progressive strengthening of associations between small pieces of foundational knowledge creating a deep understanding of the domain (i.e. McClelland, 2000). This understanding gives learners the ability to make connections internally so they can figure out novel approaches to problems. They are also able to deal with ill-structured problem spaces more efficiently (Bransford, Brown & Cocking, 1999; Jonassen, 1997). Learners at the automatic level are able to quickly retrieve the most efficient and effective solutions rather than having to go through a trial-and-error process, which in turn gives them the ability to tackle complex problems.

To foster learning across these various levels of domain knowledge, instructional systems must facilitate recognition and recall of learned content, illustrate the associations of learned and new content, and extend associations to new or novel situations. In serious game environments, which we argue are primarily player-directed, open-ended exploratory or discovery spaces, examining what is known about the needs of learners at every stage of development is critical to determine what is needed to support meaningful learning (Kirschner, Sweller & Clark, 2006).

THE IMPORTANCE OF PRIOR KNOWLEDGE IN DESIGN

As with any instructional environment, the goal of a well-designed serious game is the development and support of the learner's (in this case, player's) knowledge base. To support this development, serious game designers must be aware of research precedents associated with message design and prior knowledge of learners. Cognitive load theory (CLT; Chandler & Sweller, 1991; Sweller, 1999) provides a theoretical framework for designing instruction that uses different forms of media representations (i.e., text and pictures, text and narration) or multimedia to support the learner. CLT accounts for the load on working memory resources during each stage of knowledge development and can guide designers as they create environments to support not only novices but also learners with a higher level of prior knowledge. CLT provides empirical evidence that instructional messages are most effective when they are designed to account for the learner's cognitive system.

Using what is known about human cognitive architecture, CLT defines three types of cognitive load evidenced when instructional messages are presented to learners (Chandler & Sweller, 1991). Intrinsic cognitive load is associated with the complexity of the elements of the instructional domain and is much higher in domain novices than in experts. Germane cognitive load refers to the mental resources necessary to develop relevant schema for learning independent of the learner's expertise in the particular domain. Extraneous cognitive load is found in poorly designed instructional messages that present unnecessary details in the message, thereby distracting the learner from the instruction. These three types are additive and too much load on the learner's cognitive system is found to hinder learning at any level of prior knowledge.

In an effort to inform the field of instructional design working within a CLT framework, van Gog, Ericsson, Rikers and Paas (2005) discuss how different cognitive systems (novice vs. expert) are affected by the design of the instructional environment. They argue that in order for instructional designers to create sound learning environments for each stage of knowledge, we must attend to both the initial development of schema (novice stage) and the continuing reinforcement of domain knowledge for experienced learners (automatic stage). Leveraging findings on the effects of deliberate practice and expert characteristics, van Gog et al. suggest that as learners develop, their instructional environments should adapt to their knowledge base. They call on instructional design research to verify their assertions by creating adaptive systems. It is this ability to create an adaptive system that holds promise for the design of self-directed but meaningful exploratory learning environments like serious games (van Merrienboer & Ayres, 2005). In serious game design, this can be realized by providing concrete examples and more restricted learner controls in the early stages of learning, and gradually providing less structure and more learner control as the learner gains expertise.

Supporting Knowledge Development in Player-Driven Exploratory Learning Environments

As Mayer (2009) points out, tests of multimedia environments have shown marked differences in the way high- and low-domain knowledge users interact with instruction. Empirical research indicates that differences in levels of expertise call for differences in the design of instructional messages (Kalyuga, Ayres, Chandler & Sweller, 2003; van Gog et al. 2005). Understanding human cognitive architecture, the basis of CLT, allows us to see that as knowledge is developed, learners are able to use cognitive resources in different ways (e.g., taking on new and divergent problems). Given what we know about the stages of knowledge acquisition and the importance of adapting instruction to learners' knowledge development, serious game designers should think about evoking the behavior of experts during game play as a means to facilitate encoding of domain specific knowledge for later transfer into practice.

In the context of serious game design, we define the effective development of knowledge as a progression towards deep understanding of the domain and support once this level is achieved and the learner has become a more expert thinker. Given both the overall nature of serious games in providing a space for discovery learning and the lack of confidence many have in completely unguided discovery based learning (i.e. Kirschner et al., 2006) this is a difficult thing to achieve. Nonetheless, with the proper attention to guidelines it might be possible to create expert thinkers from serious game play.

To guide serious game designers in the behaviors we strive to evoke through continuing explorations in the serious game space, we first examined Bransford, Brown and Cocking's (1999) characteristics of domain experts. These characteristics are based on research which observed the differences between novice and expert behavior in certain disciplines (e.g. de Groot, 1965, Chi, Glaser & Rees, 1982), and are listed in Table 1. The list contains the behaviors we want to see after learners interact with open-ended exploratory learning environments (including both instructional simulations and games). Table 1 summarizes these characteristics and provides general design considerations and possible adaptations meant to support learners during their development from novice to expert. These adaptations are especially critical in serious game design where supports should be self-contained as affordances within the game environment, and they form the basic structure for the heuristics proposed in the next section.

SUPPORTING KNOWLEDGE DEVELOPMENT IN SERIOUS GAMES

Serious games are more than simple multimedia instructional environments. Many complex elements go into a well-designed game. Elements of narrative, fantasy, pedagogical structure and competition are critical for game effectiveness (Amory, 2007; Killi, 2005). Affordances such as custom avatars, inventories, non-player character interactions, tool sets, reflection journals and collaborative spaces present multiple opportunities for instructional designers to create pedagogically meaningful learning environments. As instructional designers, we think it is important to pay special attention to what past research tells us in

Table 1. Characteristics of expertise (adapted from Bransford et al. 1999) and their related supports and design considerations

Expert Characteristics	Design Considerations	Serious Game Adaptations to Support Knowledge Development
Notice patterns in problem spaces	Vary levels of problem detail and complexity to further build and extend expertise	Reduce level of overt help and increase complexity of problems as knowledge is developed
Understand domain conditionally	Domain-Related Information can be presented that take advantage of this conditional knowledge.	Gradually present problems that require less procedural and more conditional knowledge
Easily retrieve domain knowledge without expending a large amount of mental resources	Added layers of capability and tool sets can be provided to experts as it is not necessary to use mental resources to figure out problem solution paths	Gradually release more complex affordances as knowledge progresses
Approach new situations flexibly	Ill-structured problems can be solved with reduced mental resource expenditure	Increase the use of multifaceted problems that require the chunking of domain knowledge

terms of a careful balance of instructional message and supports to facilitate effective knowledge development. By designing for the support of knowledge development, we increase the chances of skills transfer from the serious game into the real world of practice.

To quickly review what we have discussed regarding research in cognitive processes and support of knowledge development, domain novices (i.e. learners in the cognitive stage) do best when presented with a high level of informational detail and guidance in a simplified but very contextual environment in order to build a mental model of necessary knowledge and/or procedures (Mayer, 2009). This sequencing and structure allows novice learners to encounter and solve each necessary procedural step in a task so that associations are facilitated and connections are strengthened (Anderson, 2000; McClelland, 2000). On the other side of the equation, learners with a higher level of domain knowledge can work in a richer representation of the problem space but with a lower level of scaffolds and supports (primarily available upon request) as long as practice opportunities are structured to support domain-relevant schema (Kalyuga, Ayres, Chandler & Sweller, 2003; Mayer, 2009; van Gog, Ericsson, Rikers & Paas, 2005). One promise of complex exploratory learning environments like serious games is that adaptations for facilitating and supporting knowledge development can be built into several different game features.

Adapting Features From Simulation Design for Serious Game Design Heuristics

The heuristics presented in this next section of the chapter deal with four critical features of exploratory learning environment design; models, interface, learning activities and learner control. These features are derived from precedents in simulation design research (Alessi, 1988; Alessi & Trollip, 2001; de Jong, de Hoog, & De Vries, 1993) and are easily adapted through the use of design heuristics.

Consider as an example, a serious game designed to train investigators in crime scene analysis. The game starts with the learner navigating a vehicle to a house where a crime has occurred. At the cognitive stage, a player might navigate the vehicle into the driveway and immediately enter the house. In contrast, a player with more expertise would begin earlier in the scenario to observe the street, the driveway and yard for tire marks, footprints, and other evidence related to the crime *before* entering the house. Varying the starting point of the game, the overt aspects of the evidence, and the amount of coaching can provide a very different amount of complexity and support to learners at different stages of expertise within the game. Without this support for knowledge development, a stand-alone serious game environment can overwhelm the novice, thus leading to incorrect and/or inefficient actions and possible misconceptions. On the other side of the continuum, serious game environments with minimal guidance will provide the right amount of challenge along for the expert investigator (Kirschner et al. 2006).

Model Feature

Models represent the underlying structure of the knowledge domain. The model may or may not be available to the learner; however, some propose allowing learners at more advanced stages to see the model in order to facilitate knowledge development (Alessi, 1988; de Jong, et al., 1993). The type, design, and fidelity of the underlying simulation model are driven by the level of realism needed to support the underlying scenario, instructional interface and learner activities. As previously stated, serious games are not constrained by reality, so this feature can be adapted as needed to support the learners.

As a player interacts with the game, their actions are reflected in reactions within the game world. When domain-related, these interactions/reactions serve as declarative knowledge items, the building blocks of understanding the connections that comprise a deep understanding of the domain. As domain knowledge develops, learners are more able to see the connections between the smaller domain-related challenges (Bransford, Brown & Cocking, 1999). By presenting these tasks gradually and with increasing elaboration and detail, we support the learner by slowly facilitating the associations in their cognitive structures (de Jong & van Joolingen, 1998).

General design heuristics related to the presentation of the model in serious game environments are:

1) Early in knowledge development, activities are very simple and straightforward to avoid complexity (high intrinsic cognitive load; Chandler & Sweller, 1991). This allows the learner to use mental resources to understand the basic structure of the domain.
2) Layers of model complexity are added gradually as knowledge develops. As the learner gains domain-related knowledge, information on how the pieces of knowledge are related (i.e. connections or associations) can gradually be revealed. This supports the strengthening of these connections that occur in the associative stage (Anderson, 2000) of developing domain knowledge.

Serious game affordances that can be designed to reflect these heuristics include:

- Inventory
- Transition narratives
- Level completion tasks

Let's take the example of the crime scene investigation training game for novice investigators as an example of how these heuristics might be implemented for the expertise continuum.

Cognitive: In the beginning stages of knowledge development, players will begin their investigation but their focus is not distracted by the presentation of how these pieces fit together. Instead, their attention is guided by narrative (e.g., via non-player characters—NPCs—or text) and the player is directed to the necessary procedures and tools (revealed in inventory) for collecting evidence. Level goals are small scale problems (e.g., "note potential evidence for further inquiry" or "pick up the magnifying glass to examine this fingerprint").

Associative: As players proceed through the game, the pieces of evidence are collected in the inventory making the underlying model of how much and what evidence to collect to facilitate the investigative process viewable. Narrative is still frequent to refocus attention and connect pieces of evidence to the deduction process. Level goals become more complex and require more than one action to complete. Guidance for actions is reduced.

Automatic: Players have full access to both evidence collection tools in inventory and the model of the deductive process showing the relationship of each piece of evidence and how they are related to the investigative process. Level goals are more complex, investigations must be resolved to level up.

Interface Feature

The most commonly recognized aspect of an exploratory learning environment (e.g. simulations and serious games) is the instructional interface that provides a text or graphical representation of the phenomenon, process, or situation being simulated. A graphical interface provides a visual image of the phenomenon, equipment, or scenario environment. In the context of a serious game, the interface refers to explanatory scaffolds and supports for task accomplishment including help from text-based cues and/or non-player characters serving as guides.

General design heuristics related to the presentation serious game interface:

1) Game instructional interface adjusts levels of help and scaffolding to account for learners knowledge level
2) Learners with a low level of prior knowledge are presented with simple tasks and explanatory scaffolds such as worked examples.
3) As learner knowledge develops, explanatory scaffolds become available on request.

Serious game affordances that can be designed to reflect these heuristics include:

- Help access
- Feedback to player

Let's go back to our example of a investigation training game to illustrate how this might work:

Cognitive: The interface appears as a simple frame of the immediate area where the player will be collecting evidence. Explanations of *each* element on the screen are provided via rollovers providing text-based or verbal explanations of necessary tools and to give the player a situational awareness of the environment (i.e. "You are standing in front of the house where a crime has occurred, the first piece of evidence is in front of you.").

Associative: As players proceed through the game, the interface view is expanded to include more of the surrounding environment, which might be distracting for players at the cognitive stage. Help and feedback via scaffolding from text or verbal messages is still available but only when critical errors occur.

Automatic: As the learner develops knowledge, the interface is fully available to the player, while scaffolds from text or verbal messages are eventually are made available only upon request.

Learning Activities Feature

The learning activities comprise the actual tasks given to the player to promote the development of their knowledge. Learner activities in a simulation may include dissecting a frog, mixing a chemical compound, docking a spacecraft, or breeding mice. Strategies for learning activities include specifying the experimental setting with initial values and parameters (de Jong, et al., 1993), explaining or demonstrating the phenomenon or procedure (Alessi, 2000), allowing the learner to choose the next step in the process or the format of data presentation and providing realistic interface and immediate feedback after learner inputs (de Jong, et al.), and giving summary feedback or debriefing at program completion (Alessi and Trollip, 2001).

In order to facilitate the development of knowledge without interfering with necessary mental resources, careful attention should be paid to the tasks given at each stage of knowledge development. At a lower level of knowledge, learners need to interact with small elements (or units of knowledge). As associations or connections develop, activities can become more complex leading to the presentation of ill-structured problems.

Design considerations related to the learning activities in the serious game environment are:

1) Learners with low prior knowledge are given simple tasks. Detailed explanations accompany tasks
2) As knowledge develops, tasks become more complex.
3) Explanations begin with high levels of detail and are given at each step of the process. As the game progresses, explanations are available on request or automatically occur if several errors are made.

Serious game affordances that can be designed to reflect these heuristics include:

- Problem statements
- Level completion tasks
- Feedback to player

Let's go back to our example of a investigation training game to illustrate how this might work:

Cognitive: Players are not simply allowed to take a course of action. Instead they are told stepwise (via text-based or verbal presentation of problem statements from a non-player character) each procedure involved in the arrival of a crime scene (i.e. look around to see if there is evidence outside the area). They are then directed to collect single pieces of evidence and these pieces are stored in an inventory. Players complete levels after they complete each small step.

Associative: As they progress through the game, units of evidence collected are combined and players are shown the collection to form a "big picture" of how single units of evidence add up to conclusions about what occurred during the crime. Players are allowed to level up after they complete larger tasks but do not have to complete the entire investigation.

Automatic: At this stage, a new complex crime scene with many interacting elements is presented. Players are not allowed to level up until they complete the entire investigation and report their findings.

Learner Control Feature

Features for learner control include affordances meant to control the flow of information in the game. These controls support knowledge development by providing necessary domain information. Because learners at lower knowledge levels need mental resources to process foundational knowledge, it is advisable to focus their attention to the domain-related knowledge. There must also be consideration for the granularity of knowledge (chunks) at this stage. At this stage, navigation should be as tightly controlled as possible. As learners gain knowledge, their mental resources are somewhat freed up and they can be gradually given access to the controls of amount and kind of information.

Design heuristics related to the learning activities in the serious environment include:

- Options for controlling the flow of domain-related information are not available for learners at the cognitive stage
- As knowledge develops, options are gradually unlocked allowing learners to control the flow of domain-related information.

Serious game affordances that can be designed to reflect these heuristics are:

- Control panels
- Navigation
- Transition narratives

Let's go back to our example of a investigation training game to illustrate how this might work:

Cognitive: Players are brought into the game and given direct instructions on how they will proceed through evidence collection. Navigational options are hidden and players are not allowed to travel around the crime scene at will. Transition narratives are very detailed indicating the next step of the procedure and any necessary situational information (i.e. you now need to look around outside the crime scene for footprints; your next stop is outside). Any evidence collection tools needed are provided directly for the learner, they are not allowed to choose. When they successfully complete small tasks, the game navigates them to the next step. In the beginning of knowledge development, players are presented with direct domain-related information in a controlled manner through the hiding or disabling of certain options (i.e. navigation to access the underlying model of the information). Navigational guidance is provided through textual or verbal feedback. Transition narratives give detailed indications of the next step in the game.

Associative: As players progress, the navigational functions such as moving back and forth from outside to inside the crime scene area are made available. Transition narratives are less detailed but are still used to provide some information to orient the player to the next task needed to complete evidence collection. Tools are available on a limited basis and feedback is provided to facilitate correct tool selection.

Automatic: Players are given full control of tools and navigation needed to complete evidence collection. Transition narratives provide very little explanation as to the next step of the task. Feedback as to the correct evidence collection procedures and necessary tools is minimal. Navigation is open and players can move around the crime scene at will.

This section presented design heuristics intended to support the development of knowledge in a serious game environment. Using features derived from design research in simulation, we were able to extract four features that are easily adaptable within a game. With these heuristics, we have striven for generality so that they can apply to a wide range of serious game taxonomies. Table 2 presents the primary serious game affordances and the adaptations needed based on these heuristics.

FUTURE RESEARCH DIRECTIONS

A still relevant criticism of the field of serious game design research is the lack of sound empirical studies documenting the advantages of learning from games. As such, it makes sense to begin a discussion of future research directions by prescribing these types of studies. In relation to the focus of this chapter, we propose the implementation of design research examining the effectiveness of the heuristics and empirical measures to determine the correlation between knowledge development and affordance adaptations recommended in the heuristics. Two separate research tracks are discussed below. One will test the effectiveness of each heuristics through controlled design research experiments. The second will test the heuristics as a whole through a process of formative and summative assessments.

Some general research questions we would like to address using the proposed research protocols are:

- Do affordance adjustments suggested by research in simulation design apply to the design of serious games?
- What is the general effectiveness of the heuristics in the design of effective serious games?
- Which affordance adjustments are most critical to effective support of knowledge development
- Is this affected by the domain?
- What other game affordances can be adjusted to support knowledge development?

Assessment of Design Heuristics

In order to verify the effectiveness of each heuristic in terms of supporting and sustaining knowledge development, we propose that each heuristic be tested in a series of controlled design experiments. The procedure for these experiments will be the same but will test each heuristic separately. Experimental conditions include variations of content knowledge and adaptation algorithms to determine the optimal progression of affordances to support the progression to expertise.

Measures

One of the greatest challenges of game research is the need for meaningful measures of learning outcomes. Research needs to move beyond measures of time in game, fun, and perception to assess gains in content knowledge, problem solving and causal reasoning which are critical for high-order activities (Jonassen & Ionas, 2008).

Table 2. Design heuristics for serious game affordances

Game Affordance	Knowledge Level	Heuristics
Inventory	Cognitive	Access to inventory items is restricted by the program. Only tools relevant to the needed task are released.
	Associative	Players allowed to select from limited items
	Automatic	Players have full access to all tool sets
Transition Narratives	Cognitive	Narratives contain detailed domain-related information Narratives provide a high level of domain related scaffolding
	Associative	Narratives contain less detailed domain-related information Narratives provide minimal domain related scaffolding
	Automatic	Narratives are minimal and only used when changing context Domain related scaffolding is available upon request
Level Completion Tasks	Cognitive	Level completion tasks represent simple procedures
	Associative	Level completion tasks are more involved requiring integration of prior knowledge
	Automatic	Level completion tasks are more complex and require the use of conditional knowledge
Help Access	Cognitive	Help is integrated into the narrative and contains a high level of domain related detail
	Associative	Help is still integrated into game narrative but level of detail is reduced
	Automatic	Help is available upon request
Problem Statements	Cognitive	Problems are reduced to small procedural steps
	Associative	Problems are more complex but are still presented in steps
	Automatic	Problem statement is complex and presented as a whole
Feedback to Player	Cognitive	Feedback is immediate, elaborative and corrective. Detailed explanations are provided
	Associative	Feedback is immediate, not as detailed. Players are encouraged to try again
	Automatic	Feedback is delayed, either available at final debriefing or on request
Control Panels	Cognitive	Access to controls is limited.
	Associative	Some access to controls released to player
	Automatic	Player given full access to controls
Navigation	Cognitive	Navigation through game space is controlled by the program
	Associative	Players are allowed to navigate restricted areas of the game space
	Automatic	Players are allowed full control of navigation

Research should also focus on the near and far transfer of problem solving and causal reasoning to other content areas and performance in related environments.

More advanced technologies today allow researchers to collect physiological data from learners interacting with computer-based and virtual learning environments to measure individual learners' response to sensory, motor, and cognitive stimuli in the simulation or serious game. Technologies such as eye tracking and electroencephalogragh (EEG) facilitate measuring visual attention and cognitive response continuously throughout game play. These physiological measures allow the researcher or developer to link the stimuli in a simulation or game to continuous attention and processing on the part of the learner, offering promise for adapting the program to individual learners. For example, in the investigation game discussed previously, if a learner is having difficulty identifying clues at a crime scene the game could highlight a set of items or fade out unnecessary details in the scene. With eye tracking, the program can detect if the learner now "looks" at the individual clues, and with EEG it can discriminate if the learner is cognitively processing that clue. Such technologies can be used to assess individual learner cognition, the effectiveness of instructional approaches, and the efficacy of supports provided to learners at various stages of knowledge development.

It is worth noting that the equipment used to collect these data continues to evolve and is still in early stages for such applications. Similarly, current research in neuroscience continues to localize neurological processing. Techniques such as event-related potential facilitate measurement of P300, which has been linked to cognitive processing (Hillyard, 2008). As these technologies advance, it is conceivable that physiological measures such as eye tracking and EEG could become commonplace even using a web camera available on most computers and a headband that can be put on by the player. In the meantime, they are research tools that allow us to literally look into the minds of learners during instruction.

Formative and Summative Evaluation of Serious Games Employing Heuristics

The traditional formative evaluation design approach iteratively evaluates the system, which results in increasingly more robust prototypes. Data from the evaluation of each prototype is used to modify both the instruction and the interface. Furthermore, evidence-based instructional intervention design isolates various attributes of the instructional environment to determine the most effective approach. So while the serious game environment is being developed and formative evaluations are conducted, the evaluation should focus on interface design and the development of simulations and representative scenarios designed to teach foundational skills and knowledge.

Evaluations should also be made of the contexts to determine if they are appealing and motivational, and whether they help develop and support the appropriate knowledge and skills. The user interface should be evaluated to determine the most effective design. The formative evaluation should begin with a review from an expert in either interview or written form, and proceed from there to a one-to-one evaluation that involves an early storyboard or prototype version of the game. Next, a small group evaluation should take place to verify that the recommendations for changes made by the expert and one-to-one evaluations have been successfully completed. The last stage of field test should then take a more complete version of the prototype that has been modified through the expert review, the one-to-one, and the small group stages of the formative evaluation. The field test will measure the efficacy of the game in the actual environment with a sample of the actual learners that will be using the game. Feedback from this last stage of field testing is conducted on a mostly completed game and may provide feedback for both the current and future iterations of the game (Tessmer, 1993).

After a final version of the game is constructed, summative evaluations can occur through checks of knowledge development using different versions of the game. Four levels of evaluation may be used to determine the efficacy of the design including (a) level 1 learner affective reactions such as like or dislike of the game, (b) learning evaluation with pre and post test assessments, (c) transfer to see if behavior has changed in the learners' environment and (d) results or the "bottom line" of measurable results such as reduction of waste or increase in production, (Kirkpatrick, 1994). Researchers must move beyond a level 1 evaluation to provide designers and decision-makers with valid research-based, data-driven reasons for allocating resources to game design and development.

CONCLUSION

As evidenced by the publication of new texts, journals and conferences specifically focused on game-based learning research, the concept of learning from playing games is beginning to cohere into a discipline of its own. In 2005, a report from the Federation of American Scientists called for a greater use of serious games for educational purposes (2005). The multifaceted exploratory learning environments afforded by serious games have the potential to transform learning. However, instructional designers are still at the beginning stages of realizing the potential for serious games. Our contribution to the growing field of serious games is to emphasize the need to look to established research on the development of knowledge (via message and interface design guidelines) and to apply these principles to some of the unique features found in serious game environments. These heuristics were carefully constructed to guide the design of what are usually self-directed, exploratory learning environments. By using existing simulation design research to construct the heuristics, we take advantage of existing research precedents.

Van Eck (2007) suggests one of the issues related to the widespread acceptance of serious game research and development is a lack of cohesion of ideas related to how game-based learning environments work as cognitive tools. He contends that as game-based researchers and designers, we must look to research from other fields to add important contributions to the pursuit of principles to make research in game-based learning a valid scientific enterprise. Research in the development of expertise not only tells us about the cognitive processes that occur while a learner gains expertise but also gives us a window into domain experts' thought processes. This information contains useful indications of what affordances are needed by learners at every stage of their knowledge development. By incorporating these findings into a typical serious game environment with all of the required affordances (story, competition, problem sets) we strengthen the legitimacy of claims for serious games as a means to deliver meaningful learning.

Our design heuristics provide instructional supports within serious game environments for the underlying model, interface, learner activities, and learner controls of the game. These heuristics are intended to create a serious environment that adapts to provide varying levels of support for learners with varying levels of knowledge. Research is needed to fully test the model and heurisics and to determine the most effective ways to implement and adapt them relative to traditional game elements such as story, narrative, fantasy, and competition.

REFERENCES

Alessi, S. M. (1988). Fidelity in the design of instructional simulations. *Journal of Computer-Based Instruction*, *15*(2), 40–47.

Alessi, S. M. (2000). Simulation design for training and assessment . In O'Neill, H. F. Jr, & Andrews, D. H. (Eds.), *Aircrew training and assessment* (pp. 197–222). Mahwah, NJ: Lawrence Erlbaum Associates.

Alessi, S. M., & Trollip, S. R. (2001). *Multimedia for learning: Methods and development*. Boston, MA: Allyn & Bacon.

Amory, A. (2007). Game object model version II: A theoretical framework for educational game development. *Educational Technology Research and Development*, *55*(1), 51–77. doi:10.1007/s11423-006-9001-x

Anderson, J. R. (2000). *Cognitive psychology and its implications* (5th ed.). New York: Worth Publishing.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes . In Spence, K. W., & Spence, J. T. (Eds.), *The psychology of learning and motivation* (*Vol. 2*, pp. 89–195). New York: Academic Press.

Baddeley, A. (1992). Working memory. *Science*, *255*, 556–559. doi:10.1126/science.1736359

Bransford, J., Brown, A., & Cocking, R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction*, *8*(4), 293–332. doi:10.1207/s1532690xci0804_2

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving . In Sternberg, R. J. (Ed.), *Advances in the psychology of human intelligence* (*Vol. 1*, pp. 7–76). Hillsdale, NJ: Erlbaum.

Crawford, C. (1984). *The art of computer game design*. Berkeley, CA: Osborne/McGraw-Hill.

de Jong, T., de Hoog, R., & de Vries, F. (1993). Coping with complex environments: The effects of providing overviews and a transparent interface on learning with a computer simulation. *International Journal of Man-Machine Studies*, *39*(4), 621–639. doi:10.1006/imms.1993.1076

de Jong, T., & Van Joolingen, W. R. (1998). Scientific discovery learning with computer simulations of conceptual domains. *Review of Educational Research*, *68*(2), 179–201.

deGroot, A. D. (1965). *Thought and choice in chess*. The Hague, Netherlands: Mouton.

Federation of American Scientists. (2005). *Harnessing the power of educational games*. Retrieved from http://fas.org/gamesummit/Resources/Summit%20on%20Educational%20Games.pdf

Foster, A., & Mishra, P. (2009). Disciplinary knowledge construction while playing a simulation strategy game. In I. Gibson, R. Weber, K. McFerrin, R. Carlsen & D. Willis (Eds.), *Proceedings of Society for Information Technology and Teacher Education International Conference 2009* (pp. 1439-1444). Chesapeake, VA: AACE.

Gee, J. P. (2004). Learning by design: Games as learning machines. *Interactive Educational Multimedia*, *8*, 15–23.

Hillyard, S. A. (2008). Event-related potentials (ERPs) and cognitive processing . In Squire, L. R. (Ed.), *Encyclopedia of neuroscience* (3rd ed., pp. 13–18). San Diego, CA: Academic Press.

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology Research and Development*, *45*(1), 65–94. doi:10.1007/BF02299613

Jonassen, D. H., & Ionas, I. G. (2008). Designing effective supports for causal reasoning. *Educational Technology Research and Development*, *56*(3), 287–308. doi:10.1007/s11423-006-9021-6

Kalyuga, S., Ayres, P., Chandler, P., & Sweller, J. (2003). The expertise reversal effect. *Educational Psychologist*, *38*(1), 23–31. doi:10.1207/S15326985EP3801_4

Killi, K. (2005). Digital game-based learning: Towards an experiential gaming model . *The Internet and Higher Education*, *8*(1), 13–24. doi:10.1016/j.iheduc.2004.12.001

Kirkpatrick, D. L. (1994). *Evaluating training programs: The four levels*. San Francisco, CA: Berrett-Koehler.

Kirschner, P. A., Sweller, J., & Clark, R. E. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential and inquiry-based teaching. *Educational Psychologist*, *41*(2), 75–86. doi:10.1207/s15326985ep4102_1

Low, R. (in press). Examining motivational factors in serious educational games . In Van Eck, R. (Ed.), *Gaming & cognition: Theories and perspectives from the learning sciences*. Hershey, PA: IGI Global.

Magerko, B., Heeter, C., & Medler, B. (in press). Individual differences in students: How to adapt games for better learning experiences . In Van Eck, R. (Ed.), *Gaming & cognition: Theories and perspectives from the learning sciences*. Hershey, PA: IGI Global.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge, UK: Cambridge University Press.

McClelland, J. L. (2000). Connectionist models of memory . In Tulving, E., & Craik, F. I. M. (Eds.), *The Oxford handbook of memory* (pp. 583–596). New York: Oxford University Press.

Reese, D. D. (in press). Games to evoke and assess readiness to learn conceptual knowledge . In Van Eck, R. (Ed.), *Gaming & cognition: Theories and perspectives from the learning sciences*. Hershey, PA: IGI Global.

Sweller, J. (1999). *Instructional design in technical areas*. Camberwell, Victoria, Australia: Australian Council for Educational Research.

Tessmer, M. (1993). *Planning and conducting formative evaluation*. London: Kogan Page Limited.

Van Eck, R. (2007). Six ideas in search of a discipline . In Shelton, B., & Wiley, D. (Eds.), *The design and use of simulation computer games in education*. Rotterdam, The Netherlands: Sense Publishing.

van Gog, T., Ericsson, K., Rikers, R., & Paas, F. (2005). Instructional design for advanced learners: Establishing connections between the theoretical frameworks of cognitive load and deliberate practice. *Educational Technology Research and Development*, *53*(3), 73–81. doi:10.1007/BF02504799

van Merriënboer, J., & Ayres, P. (2005). Research on cognitive load theory and its design implications for e-learning. *Educational Technology Research and Development*, *53*(3), 5–13. doi:10.1007/BF02504793

Zyda, M. (2005). From visual simulation to virtual reality to games. *IEEE Computer*, *38*(9), 25–32.

APPENDIX: ADDITIONAL READING

"Must-Reads" for this topic

Alessi, S. M. (1988). Fidelity in the design of instructional simulations. *Journal of Computer-Based Instruction, 15*(2), 40-47.

Alessi, S. M. (2000). Simulation design for training and assessment. In H. F. O'Neill, Jr., & D. H. Andrews (Eds.), *Aircrew training and assessment* (pp.197-222). Mahwah, NJ: Lawrence Erlbaum Associates.

Alessi, S. M., & Trollip, S. R. (2001). *Multimedia for learning: Methods and development*. Boston, MA: Allyn & Bacon.

Anderson, J. R. (2000). *Cognitive Psychology and its implications* (5th ed.) New York: Worth Publishing.

Bransford, J., Brown, A., & Cocking, R. (Eds.). (1999). *How people learn: Brain, mind, experience, and school*. Washington, DC: National Academy Press.

Chandler, P., & Sweller, J. (1991). Cognitive load theory and the format of instruction. *Cognition and Instruction, 8*(4), 293-332.

Chi, M. T. H., Glaser, R., & Rees, E. (1982). Expertise in problem solving. In R. J. Sternberg (Ed.), *Advances in the psychology of human intelligence* (Vol. 1, pp. 7-76). Hillsdale, NJ: Erlbaum.

de Jong, T., de Hoog, R., & de Vries, F. (1993). Coping with complex environments: The effects of providing overviews and a transparent interface on learning with a computer simulation. *International Journal of Man-Machine Studies, 39*(4), 621-639.

Jonassen, D. H. (1997). Instructional design models for well-structured and ill-structured problem-solving learning outcomes. *Educational Technology, Research and Development, 45*(1), 65-94.

Jonassen, D. H., & Ionas, I. G. (2008). Designing effective supports for causal reasoning. *Educational Technology Research and Development*, *56*(3), 287-308.

Mayer, R. E. (2009). *Multimedia learning* (2nd ed.). Cambridge, UK: Cambridge University Press.

Sweller, J. (1999). *Instructional design in technical areas*. Camberwell, Victoria, Australia: Australian Council for Educational Research.

van Joolingen, W. R., & de Jong, T. (1991). Characteristics of simulations for instructional settings. *Education & Computing, 6*, 241-262.

Top Texts for InterDisciplinary Studies of Serious Games

Alessi, S. M., & Trollip, S. R. (2001). *Multimedia for learning: Methods and development*. Boston, MA: Allyn & Bacon.

Beck, J. C., & Wade, M. (2006). *The kids are alright: How the gamer generation is changing the workplace*. Boston: Harvard Business School.

Gee, J. (2007). *What video games have to teach us about learning and literacy* (2nd ed.). New York: Palgrave Macmillan.

Gibson, D., Aldrich, C., & Prensky, M. (2007). *Games and simulations in online learning: Research and development frameworks*. Hershey, PA: Information Science Publishing.

Harrigan, P. (2004). *First person: New media as story, performance, and game*. Cambridge, MA: MIT Press.

Kafi, Y. (1995). *Minds in play: Computer game design as a context for children's learning*. Hillsdale, NJ: Lawrence Erlbaum.

Koster, R. (2004). *A theory of fun for game design*. Scottsdale, AZ: Paraglyph Press.

Mayer, R. E. (2001). *Multimedia learning*. Cambridge, UK: Cambridge University Press.

Shaffer, D. (2006). *How computer games help children learn*. New York: Palgrave Macmillan.

Shelton, B., & Wiley, D. (2007). *The design and use of computer simulation games in education*. Rotterdam, Netherlands: Sense Publishers.

This work was previously published in Gaming and Cognition: Theories and Practice from the Learning Sciences, edited by Richard Van Eck, pp. 152-168, copyright 2010 by Information Science Reference (an imprint of IGI Global).