A Framework for Promoting High Cognitive Performance in Instructional Games

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ABSTRACT

With the advent of gaming technologies as a method for instruction, practitioners have come to realize that gaming for learning lacks a universally accepted set of standards to both judge the effectiveness of training and inform training developers on empirically validated methods for effective instructional employment. Success stories in employing these methodologies have appeared in training literature and some principles for effective instructional games have been developed (Gee et al. 2003 - 2007, de Freitas & Jarvis 2006). However, there is not yet a commonly accepted, empirically derived set of standards available for instructional developers to describe the elements that make an effective instructional game.

This paper focuses on establishing an ontological framework for standards and guidelines in the development and employment of game-based training. To inform the discussion, the authors draw from several research and methodological sources, including 30 years of cognitive psychology literature (Anderson, 1981; Chi, Farr, & Glaser, 1988; Clark, 2008; Klahr and Kotovsky, 1989; Posner & Snyder, 1975; Schneider & Schifrin, 1977; Shiffrin & Schneider, 1977), work in Cognitive Task Analysis (Crandall, Klein, & Hoffman 2006; Klinger, 2003), and research and practical experience developing Intelligent Tutoring Systems (Anthony, 2006; Chandler, 2003) over the past 20 years. Using the proposed ontological framework as a starting point, it is expected that researchers will refine and improve upon the suggested dimensions and category levels and ultimately establish a fully specified, empirically derived ontology to be employed and used by content and instructional developers as they delve further into the world of game-based training.

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OVERVIEW

Over the last decade, the use of games for training and education has expanded considerably. This is true for serious games (e.g., America's Army) and simple gaming employed as portions of larger training programs (e.g., flash-based games). This may be attributed to improvements in computing power, the expansion of the internet, or the new generations of students and soldiers who have grown up playing video based games. As the use of gaming has expanded into schools and various military training environments, educators and researchers have naturally sought to understand the attraction of gaming and attempt to gauge its effectiveness (de Freitas & Jarvis, 2006; de Freitas & Jarvis, 2009; Gee, 2003, 2007; Roman & Brown, 2008;). Researchers have found that games can be effective for some types of skill development, often as supplemental training employed in conjunction with traditional training. For example, Roman and Brown (2008) report that games used to supplement traditional training significantly enhanced the effectiveness of the cognitive understanding of tactics, techniques and procedures (TTPs), and de Freitas and Jarvis (2006) reference various studies that provide evidence that games accelerate learning, increase motivation and support the development of higher order cognitive skills.

Despite a growing body of evidence in support of games as effective for training and education, there is no commonly accepted, empirically derived set of standards or framework available to describe and evaluate the effectiveness of instructional games. This is not to say that there is not work towards this goal. One example is a proposed development approach to game-based learning currently under investigation by de Freitas and Jarvis (2006, 2009). Additionally, Sawyer and Smith (2008) developed a Serious Games Taxonomy to clarify the nature and use of serious games and to define the current state of the Serious Games industry. Finally, Gee (2003, 2007) described 36 principles of effective techniques for instructional games.

This paper presents a specific, empirically derived approach towards establishing a framework for identifying standards and guidelines in the development of instructional games. The definition of a standard is the consistent application of cognitive psychology, learning theory, and Instructional System Design (ISD) principles and techniques to increase the likelihood that learners achieve the desired learning outcomes. With this definition in mind, the suggested framework comprises three key dimensions: level of expertise, type of knowledge and skills being taught, and type of game. Cognitive research over the last 30 years illustrates that certain techniques are more appropriate for different levels of learner expertise. The consistent application of cognitively-derived instructional techniques at the right level of learner expertise is the central dimension to the proposed framework. The type of knowledge and skills being taught is the second dimension. These two dimensions map to the type of game to use and the instructional techniques within the game as the final dimension. Although the motivational aspects of gaming are recognized as central to the attraction and success of gaming (de Freitas and Jarvis, 2009; Gee 2003, 2007), this paper does not focus on these; instead the focus is on the cognitive and instructional aspects that make various types of games effective for achieving desired learning outcomes.

PROPOSED ONTOLOGICAL FRAMEWORK

The proposed ontological framework described in this paper is designed to be a starting point to address a largely missing component of the research in game-based instruction. Once fully specified, it will act as an empirically based guide to identifying successful approaches to the employment of games for instruction. Construction of an ontological framework allows researchers to first populate the cells of the framework with existing research on games (i.e., to document, in one location, the types of games that have worked well to teach given types of skills), and then later employ the populated ontology to identify the most effective game-based training solutions for their training goals.

The development of any ontology first involves the identification of relevant dimensions. As noted above, level of expertise, type of knowledge and/or skill being taught, and type of game are the proposed dimensions for this framework. The authors acknowledge that there are other possible dimensions applicable to the construction of this framework, and that as each dimension is described and researched, there will be additions to and/or modifications of those chosen. There is also likely to be disagreement as to the level of categorization chosen; however, it is our intent that as the framework is employed and further described by researchers, these categories will be refined and further specified.

Learner Expertise is the first proposed dimension. Although there are numerous variations of expertise, this paper bases the descriptions of the novice to expert learner levels on the extensive literary review performed by Clark (2008): Novice, Oriented Performer, Proficient Performer, Crystallized Expert, and Adaptive Expert. *Type of Knowledge and Skills* is the second dimension and was selected based on cognitive and learning literature, and our experience in training and education development. The final proposed dimension is *Type of Game*. Similar to knowledge and skill types, we selected a high level category of games as a starting point to be elaborated upon and further specified in future research. Figure 1 is a partial representation of the Framework showing the relations between the three dimensions.

Figure 1. Partial Ontology Example

	Casual Games		***Serious Games***	
	Goals	Procedures	Goals	Procedures
Novice Learners	YES	YES	YES	NA
Oriented Performers	YES	YES	YES	NA
Proficient Performers	NA	NA	NA	YES

This partial representation of the proposed ontology shows how *Learner Expertise* is compared with *Type of Game* and *Type of Knowledge and Skills*. The cells may be filled in with a variety of information such as Yes and No decisions, Not Applicable approaches, and references to research that provides evidence of whether each combination of categories is effective for instruction.

The framework addresses the following instructional design questions:

1. What is appropriate for each expertise level?
2. What type of game is best suited to teach the knowledge and skills associated with a given task?
3. Within the specified game, what kinds of techniques (ISD for learner level) will give the best learning outcomes?

Expertise

Research on cognition and expertise is rich and varied. This paper has drawn from those researchers and practitioners who have concentrated on the aspects of cognition most relevant to individual learning and work performance. Much of the relevant previous work in this area deals with the structure and content of knowledge representations, cognitive processes involved in learning skill acquisition and task performance, and the differences between experts and novices (Anderson, 1981; Anthony & Ashworth, 2006; Chi, Farr, & Glaser, 1988; Klahr & Kotovsky, 1989; Klein, 1992). This paper also draws substantially from the work of Ruth Clark (2008) who summarizes and connects 30 years of cognitive research with instructional techniques that promote cognitive performance. Clark asserts that the goal of instruction is to promote a mastery of knowledge and procedural skills in a specific domain, and later enable the learner to flexibly apply existing knowledge to new circumstances. A final body of relevant work is the research and application of Cognitive Task Analysis (CTA), specifically the work on macro-cognition (Crandall, Klein, & Hoffman, 2006). Macro-cognition is composed of the high level performance aspects (i.e., functions and processes) that experts draw upon when performing in the field. If it is assumed that the end goal of instruction is to develop expertise, then CTA can be employed to not only identify the basic knowledge and skills critical to a given domain but also to determine those functions and processes essential to high performance. Ultimately, if we want people to become domain experts, then the domain-specific knowledge, processes, and functions (i.e., macro-cognition) identified from CTA are the kinds of cognitive skills learners must acquire.

Experts and Novices: Cognitive Differences

The cognitive processes which differentiate expert from novice performance have been thoroughly investigated (Anderson, 1981; Chi, Farr, & Glaser, 1988; Klahr & Kotovsky, 1989) and are briefly summarized by Anthony and Ashworth (2006). The classical notion of expertise as a generalized capability has given way to the information processing approach; specifically, to mechanisms that detail the structure and process of acquiring, organizing, storing, and retrieving information. Consider the structure of knowledge in human memory. Experts have well-organized knowledge structures which inter-relate all aspects of a domain. Their *conceptual knowledge* of goals is directly associated with the *procedural knowledge* required to attain goals, which in turn, is directly related to the *declarative knowledge* required to perform the procedures. All three knowledge types are contextualized with each other. Experts know why they are acting, how they need to act, and what supporting information is necessary to act. On the other hand, novices have sparsely populated, conceptually disorganized knowledge structures. This leads to poor performance because they do not understand the goals, procedures required to attain those goals, or the supporting information required to perform the domain procedures (Anthony & Ashworth, 2006).

There are many cognitive processes that can be described to differentiate experts and novices. One example is the processes of encoding and subsequently accessing knowledge from long term memory. Both of the processes require attentional effort. Since attention operates within working memory, it is subject to the same limitations as working memory [i.e., limited capacity in both number (2 to 4 elements) and time (12 seconds] and thus engaging in these cognitively effortful tasks (i.e., learning new skills) subsumes significant resources, leaving little for other tasks. Experts have a large, well organized repository of specific acquired knowledge. Their ability to access that knowledge is largely automated (Posner & Snyder, 1975; Schneider & Schifrin, 1977; Shiffrin & Schneider, 1977) and thus requires much less attentional resources than novices. As a learner develops expertise, those activities no longer require the undivided attention of working memory. This allows the expert to focus on a broader array of activities. Thus, experts' learning (within their domain of expertise) is more efficient and effective than novices because of these knowledge structures and their ability to readily access them to not only contextualize new information, but to subsequently facilitate its incorporation into these existing structures (Anthony & Ashworth, 2006; Clark, 2008).

Characteristics of Expertise Levels

Although there are various conceptualizations of the differences from novice to expert, Clark (2008) details five levels. The following describes the characteristics of different performance levels: Novice, Oriented Performer, Proficient Performer, Crystallized Expert, and Adaptive Expert.

Novice Learners are coming to a domain for the first time. They do not have the basic knowledge structure, nor do they possess the basic vocabulary, procedural skills, or even knowledge of what procedural skills they need.

Oriented Performers have instantiated a knowledge representation for the domain and possess academic knowledge of the vocabulary and central concepts for one or more task areas in a domain but do not have any automated abilities to work within their skill set.

Proficient Performers have a more developed knowledge representation. They have book and practical knowledge and have automated many procedural skills and can demonstrate reliable repeatable performance; they understand how a stand alone system works but not yet how it is linked to the domain; their experience base is still limited and their work is still supervised. Most people spend a significant part of their time as a proficient performer.

Crystallized Experts have a fully developed knowledge representation for one or more domain task areas including knowledge of how areas are related. The processes and procedures in the area have become fully automated. These are often supervisors, checking work, providing advice to lesser skilled workers, and helping troubleshooting and handling system specific issues.

Adaptive Experts have the big picture. They have a fully specified, inter-related, knowledge representation. Adaptive Experts have a clear understanding for how all of the components of the system work together. They have mastered most of the subtasks contributing to the total domain, and have mastered macro-cognitive processes and functions that allow their knowledge to be adapted unique situations. Within their domain, they recognize cues and patterns better then anyone; know when and how to apply processes and procedures and when and how to improvise; set goals appropriate to the circumstances; devise strategies and tactics, assess risk, plan and coordinate others to reach the required goal; and can adjust their goals as circumstances change.

Expertise Summary

The varying levels of expertise are widely researched and supported in cognitive literature and serve as the dominant dimension within the proposed framework. The subsequent dimensions are less defined and somewhat notional, as the current, available literature focus is limited; however, we urge researchers to debate and identify appropriate categorizations for knowledge and skills and types of games.

Knowledge and Skills

Research in cognitive learning identifies basic and advanced knowledge and skills. There is not a widely accepted, comprehensive list of knowledge and skill types. One potential category list comes from an educational software company listing 41 cognitive skills (in 6 categories) suggested as critical for learning (Learning Enhancement Corporation, 2007). These are: *Attention Skills* (visual sustained attention, auditory sustained attention, visual selective attention, auditory selective attention, divided attention, flexible attention); *Visual Processing Skills* (Visual Discrimination, Visual Figure Ground, Visual Form Consistency, Directionality Visualization, Visual Span, Visual Simultaneous Processing, Visual Sequential Processing, Visual Processing Speed); *Auditory Processing Skills* (Auditory Discrimination, Auditory, Sequential Processing, Auditory Processing Speed); *Sensory Integration Skills* (Oculomotor Skills, Visual-Motor Integration, Auditory-Motor Integration, Timing-Rhythm, Visual-Auditory Integration); *Memory Skills* (Visual Short-Term Sensory Memory, Auditory Short-Term Sensory Memory, Visual Short-Term Immediate Memory, Auditory Short-Term Immediate Memory, Working Memory, Visual Spatial Memory, Long-Term Memory, Visual Sequential Memory, Auditory Sequential Memory, Visual Simultaneous Memory); and *Thinking Skills* (Logic, Reasoning, Planning, Problem Solving, Strategic Thinking, Visual Thinking, Conceptual Thinking, Decision Speed).

It is clear that this is a very inclusive list. However, for the purpose of this ontology, it is too specific to be broadly applied and measurable against a larger set of task types. A better option is to consider a list with fewer categories. Klein (1992) provides a list specific to the forms of knowledge that experts and novices differ on:

- Procedures
- Specific Details
- Declarative Knowledge
- Physical Relationships
- Interpersonal Knowledge
- Perceptual / Cognitive Skills
- Perceptual/Motor Skills
- Goals
- Precedents
- Cultural Knowledge

As a starting point, this list is a more attractive option to include in the ontology as it is both measureable and previously shown to specify the differences in experts and novices.

Knowledge and Skills Summary

Although Klein (1992) is recommended as a starting point for this ontology, it is expected that researchers and practitioners will debate and ultimately identify the most appropriate and empirically useful level of knowledge and skill categorization applicable to this framework. This list should contain a fundamentally agreed upon set of basic knowledge and skill types taught in most domains, and not be too general, nor specific, to avoid difficulty with measurement and evaluation of those knowledge and skills (i.e., a list that is too general or specific may not lend itself to reliable measurement).

Types of Games

Given the cognitive differences between expert and novice learning and that the types of knowledge and skills that each need for optimum instruction may differ, it is reasonable to assume that different types of games teach different types of skills to different levels of learners. For example, an action packed, complex environment, might actually help experts integrate and apply existing skills to a new context or situation (e.g., determining how to treat wounded using limited number of medical items), while the same environment results in overload for novices. Similarly, novices would benefit from a Simple game that teaches the uses and layout of buttons on the same pieces of medical equipment, while experts have no use for such instruction.

Table 1 includes a candidate list of game types and briefly describes the types of instruction that they may facilitate. We have not included Serious Games as its own category of games as we recognize that any category or genre of game can be considered for its entertainment or education/training value. The list below includes many commonly accepted types of games, as identified by game developers; however, the list is neither inclusive nor specific of every type and configuration of educational or instructional game available. These categories are intended as a starting point for the game dimension. It is anticipated that researchers and instructional game developers will proactively work together to identify the most appropriate category level for this dimension. Finally, we recognize that other variations within type of game (e.g., player point of view, team or single player options, and online versus console video games) are not included in the proposed list but should be considered.

Table 1. Game Types

Game Type	Description
Simple Games	Games that teach vocabulary, object recognition, orientation, and problem solving (e.g., Jeopardy, Hang-man, Bejeweled))
Action Games	First person shooters and team-based games that teach a mix of tactical, strategic or adventure elements (e.g., Tomb Raider, Call of Duty)
Strategy Games	Games that teach resource management, trade-offs in time or money or raw materials (e.g., Age of Empires, Command and Conquer)
Simulation Games	Games that simulate complex machinery (e.g., aircraft, tanks)
Sports Games	Games that teach rules of sport or engagement and enable player to learn/play in different roles
Educational Games	Games that teach basic math or grammar skills and are generally aimed at younger audiences

List of game types and descriptions of each.

Ontological Examples of Instructional Techniques and Game Types for Each Expertise Level

Novice Learners to Oriented Performers: The main goal for instruction for novices is orientation. The instructional goal is to lay the foundation for the knowledge structures (i.e., mental models) that the novice will adopt and subsequently augment with new knowledge. It is critical that the foundational mental model be correct (i.e., a validated structure of the memory representation is accurate). For this reason, techniques to manage working memory load and support attention is critical. For example, presentations must be clear and concise with key concepts highlighted using minimal visual and auditory distractions. Games, consequently, must be simple in nature and incorporate basic cues that highlight fundamental processes and concepts, and be relatively free of distractions.

Oriented Performers to Proficient Performers*:* The average time span for a learner to gain expertise within a domain is 10 years (Clark, 2008). Most learners reside within Oriented and Proficient Performer. Some aspects of the learning continuum are learning new aspects of the domain to pick up new concepts, vocabulary, and procedures. Here, activating existing knowledge structures in order to integrate new information is important for efficient learning. It is at this stage that processes and skills are mastered and automated, making room for handling larger more complex aspects of the domain. One instructional technique best suited for promoting proficient performance is deliberate practice. Deliberate practice (Keith & Erickson, 2007) is an essential component of skill mastery and games at this level do not have to be fully immersive or scenario driven to be effective. Games that promote deliberate practice hone specific skills through targeted repetition, observation, reflection and feedback.

Proficient Performers to Crystallized Experts: Complete automation of the requisite skills for the task area, knowing how and why something works, mastery in reasoning and troubleshooting within the task area, are expectations of crystallized experts. A crystallized expert knows how to manage attention, identify leverage points, maintain common ground with a given team, manage risk, and improve explanations and their ability to mentally simulate (Crandall, Klein, & Hoffman 2006).

Key instructional techniques best suited for promoting crystallized expertise include training for understanding by employing varied context examples and practice (incorporating the why's and how's into worked examples and using inductive instructional techniques), teaching skills in context as expertise is tightly wedded to specifics application settings, and emulating the performance environment as closely as possible to promote the transfer of specific skills.

Virtual simulators or serious games are appropriate for deliberate practice in areas where skill proficiencies are lost quickly, are uncommon or are hazardous situations preventing regular practice. Serious games can also embed the learner in simulated situations that exercise and coach learners in macro-cognitive processes needed as a prerequisite for adaptive experts.

Crystallized Experts to Adaptive Experts*:* A challenge to crystallized experts is sometimes their inability to break the context barrier (Clark, 2008). Being able to apply principles creatively in new context relies on meta-cognitive functions. These functions include setting realistic goals, monitoring progress and recognizing limits to your knowledge. Adaptive Experts need opportunities to practice and then be coached on macro-cognitive functions such as sense making, naturalistic decision making, planning, problem detection, adaptation, and coordination (Crandall, Klein, & Hoffman 2008).

Instruction for adaptive expertise means exposing the learner to a variety of circumstances where they must solve unique problems. Some instructional techniques for promoting proficient performance are training for the principle of convergence. That is applying and teaching the same principle in several different contexts where examples vary on surface features but are consistent in deep structure. Other objectives for adaptive performance include promoting self-regulatory skills (e.g., goal setting, planning, monitoring, and reflection), training for adaptive mental model development, and promoting appreciation of contextual sensitivity

Rich, scenario based serious games benefit the learner transitioning from a crystallized expert to an adaptive expert. Immersive, complex environments that enable learners to apply their existing knowledge to new contexts are the perfect target for these learners and skill types.

Alternative Dimensions

Work should not only focus on validating the chosen dimensions and populating the framework, but must include the consideration of other potential dimensions to refine the overall framework. These include: fidelity level of instruction, employment of games as stand-alone or supplemental training, and perhaps incorporating recent research findings that suggest certain types of games stimulate specific areas of the brain (Feng & Spence, 2008).

Training Fidelity

Research in cognitive fidelity for example, (Goettl, Ashworth, and Chaiken, 2007) is an important area with implications for this work. Essentially, this research details that for the most efficient and effective instruction, different types of fidelity are required for different levels of learner expertise. High cognitive fidelity (i.e., aspects of the training environment that mimic the cognitive components of the task being taught) is important for all expertise levels, but especially for novice learners during the initial phases of instruction; while high physical fidelity (i.e., aspects of the training environment that mimic the way the real world task looks in the real world) are more effective for experts late in training. Instructional games can employ both cognitive and physical fidelity to varying extents, and these should be applied appropriately to promote efficient and effective instruction.

Supplemental or Stand-alone Training

As described above, some studies (e.g., Roman & Brown, 2008) found that games can be effective as supplemental to existing or traditional training, versus serving in a stand alone capacity. In fact, it seems a reasonable assertion to suggest that at this point, some skills can simply not be taught or practiced in a game or virtual setting (e.g., a surgeon cutting into human tissue, experiencing bullets and shells dropping around you, driving a tank or flying an aircraft).

Emerging Research

Finally, research is emerging that shows how specific brain and learning systems can be positively affected by games (e.g., Feng & Spence, 2008). As this area of research gains more support and validity, it could be beneficial to include the specific brain systems impacted by various types of games. This school of thought might serve as a valuable dimension to include in the framework.

SUMMARY AND FUTURE WORK

This paper describes an empirically-based approach to developing an ontological framework for evaluating the effectiveness of games for instruction and ultimately helping content and instructional developers select the most effective methods for meeting learning objectives of their target audiences. The proposed dimensions represent a first attempt at identifying the most important dimensions necessary for establishing a valid framework. When developing a framework of this type, researchers often debate the make-up and categorical level of proposed dimensions for extended periods of time. Thus, it is anticipated that researchers in instructional games and cognitive psychology will do the same for this ontology; debate and identify the most appropriate dimensions and categorical levels for each.

Once the ontology is developed, instructional developers will use the fully specified and populated ontology to identify the best medium for a given training goal. By first employing a valid technique (e.g., CTA) to identify the relevant knowledge and skills to be taught, and subsequently combining this with the targeted level of learner and the type of game best suited to teach the skills to that level of learner, effective and efficient learning can be achieved using the motivational medium of games.

Today's learners are no different than learners of the past; they simply have new and exciting ways to learn. Researchers and practitioners today must continue to exploit this growing medium and employ such technology to improve the overall learning process, regardless of the learner level and required skill sets. It is equally important that this is done by employing empirically validated and reliable instructional approaches. While there is no current, commonly accepted, empirically derived set of standards or framework available to describe and evaluate the effectiveness of instructional games, this ontology serves as a starting point from which to establish a credible standard to achieve these goals.

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