

Applying High Cognitive vs. High Physical Fidelity within Serious Games

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ABSTRACT

This paper establishes a framework and guidelines for determining the right fidelity for positive learning transfer within serious gaming environments. We characterize types of activities found in several video gaming environments that lend themselves to promote skills for high cognitive functioning in complex domains and then analyze what type and level of fidelity would be required for successful learning transfer. To inform the discussion we draw from several research and methodological sources. The work in Cognitive Task Analysis (Crandall, Klein, Hoffman 2006, Klinger 2003) informs our definitions of what it means to perform at a high level of proficiency. The work of Goettl, Ashworth and Chaiken (2007) establishes the differences between high cognitive and high physical fidelity; the research and practice in developing simulation Intelligent Tutoring Systems (Chandler, Owens 2003, Anthony, Ashworth 2006) highlights cases when the type and level of fidelity enhances or inhibits learning transfer. The paper introduces a framework to establish standards and guidelines for optimal learning transfer within gaming environments spanning a variety of types and levels of fidelity.

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INTRODUCTION

Advancing technologies have allowed trainers to develop realistic environments to use in training a wide variety of tasks. As those technologies have matured, much of the effort has been placed in making those simulated environments more “realistic”. Technologies are often applied for technology’s sake. The idea of experiential learning took off and simulation facilities were built to give trainees a “life like” experience with the belief that more experience in those situations resulted in learning. These systems provided an environment that was very high in physical fidelity. Simply stated, they looked and felt real. Many of these high physical fidelity environments were, though, missing an important ingredient. The link to cognition, what cognitive competencies are employed to accomplish the task and how people actually learn these cognitive competencies often fell by the wayside. There has been much change recently as trainers are working hard to develop training that teaches cognitive skills while still possessing the right level of physical fidelity (“realism”). This concept of cognitive fidelity is quickly gaining momentum and can be applied across a wide variety of medium. This paper looks at ways to infuse cognitive fidelity into training paradigms used today, specifically into the use of games for training.

High Physical Fidelity Sometimes Misses the Cognitive Mark

An example may help to illustrate the notion of cognitive fidelity. A few years ago, a member of our team traveled to an Army base to participate in the training of a unit that was about to deploy to Bosnia (see Klinger and Harris-Thompson, 2004). This 3-week training event was quite impressive. The soldiers essentially “moved in” to the barracks on the base that were made to look like barracks in Tuzla, Bosnia. Displaced Bosnian Civilians were flown in to live in this area as well, adding to the physical fidelity of the environment. Over the next 21 days and nights, soldiers completed a series of important tasks such as setting up road blocks, dealing with crowds, and reacting to violent attacks against them as well as attack

against civilians. The unit then flew to Bosnia to begin their mission.

Upon arrival in Bosnia, it was immediately clear to them that they had just received training for a very different mission than the one they would complete. Their job in Bosnia was to ensure “safe and secure passage” of all vehicles on all major roads. They dealt with local civilians regarding issues of plumbing, lack of food, and housing. Their training in setting up roadblocks was counter to their mission. Once deployed, they were faced with making decisions that were far different than those for which they were trained. They were ill-prepared to determine how best to help displaced civilians find shelter and to deal with civilians who were far less hostile toward them than they expected. This made it difficult for them to determine exactly where a threat may come from given that their training did not match the decisions and judgments they would have to make. Their training ranked very high in physical fidelity, but not very high in cognitive fidelity.

Cognitive Fidelity Vs Physical Fidelity

There are a few definitions of cognitive fidelity that will help guide and evaluate the impact games have on learning. Baxter and Lunsford (2005) discuss cognitive fidelity in terms of placing individuals into realistic situations so that their decisions are based on what they would really know and expect. Goettl, Ashworth and Chaiken (2007) describe it as “high conceptual similarity between training and performance environments,” and discuss numerous examples of successful training with very low physical fidelity, but high cognitive fidelity systems (the most famous being the Space Fortress task – Gopher, Weil, and Dareket, 1994). Cognitive fidelity is much more difficult to evaluate. Physical fidelity is much easier to measure. For example, flight simulator cockpits look very much like actual airplane cockpits. Their hydraulic “legs” allow the simulator to pitch and roll in ways that quickly fool pilots in training into feeling like they are actually flying. Yet, how does one evaluate cognitive fidelity?

If the training has high cognitive fidelity, then the cognitive demands in the training resemble the cognitive demands in a real life task (Gopher 2006). High cognitive fidelity is generally thought to have deep structure. This deep structure is the underlying conceptual or functional representation of the task and is independent of physical features (Geotl, et. al, 2007). For example, the color and shape of the buttons on X-ray equipment for screening and explosive detection are the physical surface features of the equipment. The fact that the equipment provides different techniques for identifying different types of threats is the deep functional structure of the equipment independent of color of the buttons. A person, who understands the deep functional structure of how to use the different techniques to reveal a threat, will be able to quickly adapt to different machines with the same functional features but different physical features.

High cognitive fidelity has both a conceptual component and a performance component. The conceptual or functional component is what is understood, the knowledge part. The cognitive processes component is the skill that needs to be mastered for top performance of the task. For example, an expert security officer has a good understanding of how the different techniques reveal different threat materials. They have also developed their perceptual skills to detect threatening materials no matter what orientation they are found in the bag. The measurements of whether or not high cognitive fidelity has been reached in an instructional setting are the performance outcomes.

Real world task performance is a direct result of the training independent of high or low physical fidelity in the training. Some tasks may need an extremely high level of physical fidelity, others may not. In the Bosnia example above, the expensive application of a high physical fidelity environment alone did not prepare the soldiers for the mission they faced. In fact, a very low physical fidelity training was introduced after they deployed that was shown to dramatically improve performance. In that example, a very low-tech decision-making game was developed that placed individuals into situations much like they experienced in theater. These scenarios mimicked events that had actually taken place and were developed following CTA interviews with identified experts who had been involved in those real world events. Their feedback was included in the training system so that trainees could see what the experts did (e.g., how they acquired information, how they interpreted it, and lessons learned). In this case, low physical fidelity was

appropriate. In other cases high physical fidelity may be required in order to get the trainee into the proper mindset so that the high cognitive fidelity training concepts can be applied. According to Goettl et. al. (2006) high physical fidelity is most effective for experts in late training.

THE FRAMEWORK

Cognitive Performance

One of the goals of defense training is consistent top performance of individual warfighters and teams of warfighters in complex high risk environments. Warfighters train both physically and mentally to prepare for top performance. Research shows that the mind needs similar exercise and deliberate practice in performance of cognitive tasks, just as the muscles of the body need to exercise and practice for strength and control (Gopher, 2006).

High cognitive performance is composed of attributes, such as, positional awareness, the ability to make fast good decisions, special perception, the ability to control and allocate attention and to predict what is going on (Gopher, 2007). Crandall, Klien and Hoffman (2006) in their work on Cognitive Task Analysis (CTA) identified several macro-cognitive process and functions that can be the foundation for a cognitive fidelity framework. The processes they identify are:

- Managing attention – the ability to filter and prioritize what one focuses on
- Identifying leverage points - the ability to identify opportunities and turn them into courses of action
- Maintaining common ground – the continuous maintenance and repair of calibrating understanding among members of a team
- Managing uncertain risk – the coping skills for being able to decide and act in the face of missing data, data whose validity is unclear, ambiguity over competing situation assessments, and complexity that interferes with sense making
- Developing mental models – is the ability to view a mental image or model based on abstract knowledge, concepts or principles, and often merged with contextual memories or the perceived situation, to reason about possible outcomes
- Mental simulation– the ability to run a mental model to project and analyze possible outcomes
- Story building – the ability to recreate what “must have occurred” or invent “what could happen” as a way to organize data and events, explore

alternatives, hypothesize, reason about them, and justify conclusions.

The functions to which these processes are applied are:

- Sensemaking – understanding what has or is happening in a given situation.
- Naturalistic decision making – relying on experience and the above process to identify plausible courses of action
- Planning – the process of proposing actions to transform a current state into a desired future state
- Problem detection – the ability to spot potential problems at an early stage
- Adaptation/ re-planning – the ability to reframe the situation and renegotiate goals when one realizes that the original goal has been compromised
- Coordination – the ability to orchestrate the sequencing of team actions to perform a task

Training for cognitive competencies means adapting the general cognitive processes and functions listed above to a specific domain or mission within a domain. The pilot, the Bosnian soldier, and the security officer are all making sense of a situation, planning, detecting problems, adapting and coordinating, but the specifics of the cognitive abilities applied differ from domain to domain. Cognitive Task Analysis (CTA) methods uncover what it means to be an expert within the domain. CTA points to decisions and judgments and the underlying elements of cognition involved in a given task. Elements of time pressure, high stakes, and uncertainty, all impact how individuals generate situation awareness, process information, solve problems, and develop workarounds in order to get things done. CTA uncovers these elements which should be the driving force for the development of training requirements for serious games.

Cognitive Simulations and Expert Development

The pursuit of expertise is the process of honing general abilities into specific skills, competencies and knowledge for that specific domain. Daniel Gopher and his colleagues (2007) working first with Israeli fighter pilots and later with professional basketball players showed that cognitive performance can be substantially improved with training and specifically with cognitive simulations. As described above, cognitive practice is like a mental muscle and must be exercised on a regular basis in order to maintain skill level at top performance. While cognitive fidelity is essential for early training to develop good mental models of the domain (Goettle et al. 2006, Clark 2008), deliberate cognitive practice on domain essential

abilities is critical through out expert development and maintenance (Gopher, 2007, Ericson 2003). High Physical fidelity is essential when orientation and automation of skills are dependent on the exact replica of equipment or environmental factors (Goettle et al. 2006).

In a video game, the specific objects manipulated during play may not closely map to the physical representation. People may be represented as circles or triangles for example. What is important for the learner to observe is the movement of the iconic people, not that they look like people. Research has found (Clark, 2008) that people are comfortable with the use of iconic representations, and in fact, when first being introduced to domain concepts, the iconic representation is less distracting than a full blown simulation of a realistic setting. High end graphics and ambient sound can diminish learning outcomes, especially for novice learners (Clark 2008) or it may, as in the case of the training for Bosnia, obscure the true learning requirements. Cognitive simulations that convey one central instructional objective is optimal for early learning. As expertise is developed cognitive simulation can combine more than one cognitive skill element.

Good cognitive simulations must capture the deep structure – the domain competencies – that underlie top domain performance. It is not easy to get at the underlying cognitive competencies. Cognitive Task Analysis uses a number of different knowledge elicitation methods (Crandall et al., 2006) to obtain information about what people know and how they know it. For example structured interviews, concept mapping, story telling, field observations, think aloud problem solving, are a few of the techniques. These can be used to elicit judgments, strategies, knowledge and skills that underlie performance. In our Bosnia example, experts, operating safe passage missions in Bosnia, were given structured interviews to illicit how the experts acquired information, how they interpreted it, what they did with it and the lesson they learned.

A Definition of Standard

The definition of a standard, for the purpose of this paper, is the consistent application of Instructional System Design (ISD) techniques to increase the likelihood that learners achieve the learning outcomes. Cognitive research over the last 30 years (Clark 2008) has shown that certain techniques are more appropriate for different levels of learner expertise. Techniques appropriate for experienced learners are not necessarily appropriate for novice learners. The consistent

applications of instructional techniques, at the right level of learner expertise, without undermining the inherent motivational strengths of the gaming environment are the standards being developed, in this paper. The challenge is applying good ISD standards without undermining the inherent motivational strengths of the games.

In concert CTA and ISD can help determine the right fidelity balance for instruction. CTA is used to elicit what the cognitive performance objectives are and ISD takes into consideration the best instructional techniques for the level of expertise. Together the two disciplines can begin to formulate best instructional practices for learning transfer including the right cognitive and physical fidelity for instruction.

Designing for the Right Fidelity Balance

Cognitive Fidelity is less a continuum between low to high fidelity. Rather it appears to be a change in focus from a specific single cognitive task to a multiple integrated cognitive task. What changes is how narrowly focused the cognitive aspects of the training is and what level physical fidelity is required to invoke the cognitive performance needed. From the perspective of cognitive fidelity the criterion for success is - Has the deep structure functions and processes been captured in the training or not? This is a difficult question to answer and the measurements tend to be indirect. Crandall et.al. (2006) consider cognitive measures as the “rulers by which proficient performance (human and/or system) is gauged.” (p.230). The Gauges are: enhanced perception, recognition, or comprehension, accelerated proficiency, enhanced capability to recover from error or cope with rare tough cases. Other indicators are reduced time and effort on a task, reduced mental work load, reduced frustration; teamwork is faster and more accurate, the missions are being accomplished, the schedules are being met. More research needs to be done in this area so that, during the design process, practitioners can better discern whether or not the deep structures have been being captured in their instruction.

When designing training for physical fidelity, a key consideration is the level of expertise of the learner because that influences how much cognitive load can be placed on the learner. High physical fidelity tends to increase the cognitive load and a more expert learner can handle more cognitive load. This consideration may influence the design of the game from simple and focused to complex and elaborate. From the perspective of physical fidelity the question is “What level of fidelity is needed to invoke the cognitive performance

needed?” From a cost perspective, a lower physical fidelity may be just as effective cognitively at much lower cost.

In the examples below, we begin to frame the cognitive/ physical fidelity continuum. Table 1 is a fidelity matrix. Cognitive fidelity is divided into a single cognitive task focus or a multiple, integrated cognitive task focus. Along the physical fidelity continuum, it is divided into low fidelity, targeted high fidelity and broadly high fidelity. The instructional objectives and design considerations for each cognitive and physical fidelity combination is described followed by at least one serious game example.

Table 1: Fidelity Matrix

Fidelity	Low	Targeted High	Broad High
Single Focus	Low Physical Fidelity, Single Cognitive Focus	Targeted High Fidelity, Single Cognitive Focus	Broad High Fidelity, Single Cognitive Focus
Multi Focus	Low Physical Fidelity, Multi Cognitive Focus	Targeted High Fidelity, Multi Cognitive Focus	Broad High Fidelity, Multi Cognitive Focus

Single Cognitive Task Focus, Low Physical Fidelity

In the novice expert literature (summarized in Clark 2008), novices need a focused uncluttered presentation of material so that they can correctly and unambiguously develop mental models of that domain. Games designed to teach conceptual understanding through simulation should focus on one conceptual phenomenon rather than multiple phenomena. In addition, conceptual learning is more successful when iconic representation is used rather than realistic representation (Gopher, 2006, Clark, 2008). The realism is actually a distraction obscuring the development of the underlying deep functional structure. Simple games that focus on experimenting with one phenomenon are recommended for early conceptual learning. The Reflections Game (Chandler, Chaille 1993) that taught the concept, angle of incidence equals the angle of reflection, and DynaTurtle (1981) that taught motion in a frictionless

space are examples of single cognitive task focus and low physical fidelity.

In the Reflections game, a simple iconic rectangle of flat mirrors facing each other provides students, age 12, with the ability to shoot light beams at the mirrors. The goal of the game is to angle the light's reflection in such a way that it hits a target (scoring points). Processes highlighters are used to emphasize the angle of incidence equal the angle of reflection. They focused the experimental group's attention on the relevant aspects of the concept. Study results showed 68.5% of the experimental subjects demonstrated preliminary to full understanding of the reflection concept while only 18.85% of the control subjects, who played the game without process highlights, demonstrated the same level of understanding. (Chandler, Chaille 1993 p. 254). The experimental group also demonstrated more varied and more sophisticated playing strategies during the game. Highlights, it is thought, facilitated the subjects ability to draw upon their domain knowledge, promoted self reflection and promote their ability to generalizing explanations of their observations.

The DynaTurtle microworld, developed by the MIT Artificial Intelligence Lab was designed to challenge the everyday intuitive notions of motion with a series of games that simulated the frictionless world of Newtonian dynamics (White, 1981). The instructional objective was to alter students mental model of motion with the more theoretical conceptualization of motion required for Newtonian physics. The Dynaturtle games gave students specific goals that focused their attention on specific aspects of Newtonian dynamics. "For example, many students in this study had incorrect ideas concerning how forces would affect the speed of motion." (White, 1981, p.11). The series of games improved the students ability to solve dynamic problems but what was even more interesting is that playing the games revealed to the researchers other conceptual misconceptions the students were having about dynamics that had not been apparent before.

Single Cognitive Task Focus, Targeted High Physical Fidelity

For one to progress from novice through various stages of performance to expert, a long deliberate accumulation of knowledge and targeted practice on different cognitive and physical competencies is required. Erikson (2003) calls this deliberate practice. Deliberate practice is cognitive or physical tasks just beyond the current level of competence that through a few hours of focused attention one can master.

Practicing scales in music is a good example. These are tasks with a single cognitive focus but certain aspects of the representation needs to have high physical fidelity in order to trigger the right feel or recognition aspects of the task. For example, in a game where one must recognize the difference between threat objects and non-threat objects (e.g., knife or comb, bomb or radio) as bags move through a security checkpoint in an airport, high physical fidelity of the contents of the bag as it goes through the simulated screening area is essential. The rest of the screening equipment probably does not need high physical fidelity for the recognition task but the screened contents do.

Single Focus Cognitive Task, Broad High Physical Fidelity

When training for automation of procedures or equipment manipulation skills, the cognitive or physical tasks are often highly focused to achieve automated proficiency and the physical fidelity is high to aid in recognition of such aspects of the equipment or procedure such as button layout, recognition of appropriate responses, etc. Taking the example of the threat simulator again, if the purpose is to teach the manipulation of a specific piece of equipment in addition to threat and non-threat recognition then high fidelity of the equipment as well as X-ray of the bag content is essential to effective training.

Multi Integrated Cognitive Tasks, Low Physical Fidelity

Most cognitive tasks require multiple coordinated cognitive and physical skills. Managing attention, identifying leverage points, running mental simulations; these are cognitive processes that occur simultaneously in a coordinated fashion to achieve a specific individual or team goal. When trying to perfect performance in multiple coordinated cognitive processes, high cognitive fidelity and low physical fidelity is required so that the underlying deep structure and processes are apparent. Games for honing coordinated cognitive skills such as the professional basketball game Intelligym (Gopher, 2006) have these fidelity features. Intelligym uses icons of home and opposing teams to practice different plays. It exercises attention, special perception, fast decision making and team common ground in the contexts of practicing different team movement and play. This and Similar cognitive games for fighter pilots have shown to increase performance by 30% and flatten performance decline due to fatigue (Gopher 2006, Gopher, D., Weil, M., & Bareket, T., 1994). Another class of games that employ multiple

integrative tasks and low iconic physical fidelity are the games that exercise mental visualization, reasoning and strategizing in the context of command and control strategic and tactical decision and judgment.

Multi Integrated Cognitive Task, Target High Physical Fidelity

Another set of games designed to rehearse coordinated cognitive skills where certain aspects of the simulation need to have high physical fidelity are the class of games that promote recognition, reasoning and troubleshooting skills. The fidelity of the game needs to be high to give correct information and feedback critical to performance (e.g., such as in a game to teach troubleshooting helicopter faults where the indicator light turning on at the right time in the right sequence is critical to correct diagnostics (Chandler, Owens, 2003). Similarly, games for cultural interaction and judgment require high cognitive fidelity where certain aspects of natural language expression and natural reaction of agents are critical to practice in the nuances of cultural interpretation. Bell and McNimera reference this particular cognitive activity as high cultural fidelity. (Bell and McNamara 2005). While not all areas of physical fidelity need to be high, areas supporting cultural nuances such as physical expressions may need to be high to be considered authentic.

Multi Integrated Cognitive Task, Broad High Physical Fidelity

Any designer of a game, because of the computer presentation limits, has to make choices on what to highlight with high physical fidelity and what to deemphasize as visual props. The choices in good design are where the attention of the learner should be. The fine line between full realism and targeted realism is a tough one. Full realism can be cost prohibitive and if not completely successful, worse than if realism was not mimicked. On the other hand, targeted realism can run into trouble when functionality is stubbed because the focus of the instruction is not on that area, yet the participant, familiar with the system, gets hung up because the system does not exhibit complete realism. Sometimes making an interface iconic rather than true to the real apparatus relieves the burden of both designer and learner of evaluating the authenticity of the representation. What does matter is the functional interaction. If cars are not supposed to drive through buildings, then they should not. If there are certain operational expectations, those operational rules should be obeyed.

Where the line is drawn between complete high physical fidelity and targeted physical fidelity should take into consideration other factors beyond just performance outcomes. For example, Americas Army (2009) strives to be as realistic as possible. There are many important multi-integrated cognitive tasks that the learner is learning with their team in this fully-immersive game, but one of the primary objectives of Americas Army is recruiting. The decision for high fidelity is to give the potential soldier a complete visual experience of what it might be like in the Army; not to necessarily teach with high accuracy specific skills. That is reason enough for the investment for complete immersive high physical fidelity.

Concluding Remarks

High cognitive fidelity alone does not produce good learning transfer. A clear understanding of the cognitive process and functions involved in the task is necessary to ensure learning objectives are met. Cognitive Task Analysis can facilitate capturing cognitive fidelity. Cognitive oriented instructional systems design is then needed to tailor the learning objectives to the right mix of cognitive and physical fidelity. These factors are dependent on the expertise of the learner and the desired learning outcome. We have looked at cognitive fidelity as less a continuum and more of a point of focus. Distinguishing between a single focused cognitive task to be learned or multiple integrated cognitive tasks to be mastered. We also began to setup a design framework for finding the right fidelity balance.

Single cognitive focus tasks and low physical fidelity are well suited for augmenting mental models with new learning concepts or automating narrowly focused skills. In these conditions the novice learner needs maximum focus on the basic elements of a learning objective. High targeted physical fidelity needs to be introduced when recognition of surface features are essential for performance. As we move from mastering a single cognitive task to integrating multiple tasks, low physical fidelity is again used to make apparent the underlying deep functional structure of the cognitive processes and how they interrelate to each other. High physical fidelity is introduced when precise and realistic perceptual information is required for performance mastery. The degree of realism needs to be weighed against whether or not the realism distracts from or enhances learning outcomes. Other factors, such as cost and the desire for socialization, also need to be factored into decisions for the use of high physical fidelity.

This paper has initiated a framework in which to think about the appropriate balance between cognitive fidelity and physical fidelity within serious games. Best practices in serious game development is more likely when an ISD process is followed that captures the cognitive processes in a task through CTA, takes into consideration the level of expertise of the learner, then evaluates the level of physical fidelity needed to achieve performance.

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