Cognitive Science Implications for Enhancing Training Effectiveness in a Serious Gaming Context

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Serious games use entertainment principles, creativity, and technology to meet government or corporate training objectives, but these principles alone will not guarantee that the intended learning will occur. To be effective, serious games must incorporate sound cognitive, learning, and pedagogical principles into their design and structure. In this paper, we review cognitive principles that can be applied to improve the training effectiveness in serious games and we describe a process we used to design improvements for an existing game-based training application in the domain of cyber security education.

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1. INTRODUCTION

In traditional approaches to education and training, the burden of communicating course material rests with the instructors. Over the past thirty years, more flexible, student-centered teaching methods have been advocated, inspired by the concepts of "discovery" learning [Bruner 1966; Hermann 1969] and "active" or "autonomous" learning [e.g., Johnson et al. 1991]. These instructional approaches propose replacing or complementing traditional lectures with active learning experiences such as role-playing, simulations, self-paced or team-based exercises, and other types of open-ended problems requiring critical or creative thinking. While these methods have been successfully established in many educational settings, their benefits have not been automatic and have been realized only through substantial effort [Felder and Brent 1996].

Computer-based training (also called distance learning, electronic learning or e-Learning) has had a similar progression. Deriving from largely behaviorist computer-

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based instruction paradigms, e-Learning applications still tend to reflect passive, rather than active, student-centered training philosophies. Originally following a substantially linear process, computer-based training approaches are becoming more student-centered as a result of new methods and computer technologies that allow greater flexibility in the design and delivery of instructional material. Nevertheless, many training applications that employ state-of-the art multimedia technology that allows students to interact with simulations, animations, video, and sounds still fail to meet their expected training potential. Implementation of multimedia-based training features may give the impression of engaging the student in more active forms of learning, but sophisticated use of multimedia features does not necessarily produce the desired effect. As Michael Allen (2002) observes in a well-articulated article advocating discovery-based e-Learning: “Lurking behind many of today’s slick delivery systems are shop-worn, passive learning paradigms that Socrates spurned in the fifth century B.C.”

Arguably, many e-Learning applications suffer from the traditional linear, expository teaching method in which material is presented for students to read, followed by testing for rote memorization, and then the cycle is repeated. It is not uncommon for students to breeze through such computer-based training without really learning the material, particularly when they can take advantage of user-centered features like quizzes that allow them to take another guess or casually link them back to review the material containing the correct answer. Such features are good, but not sufficient to overcome the drawbacks of otherwise passive learning formats. What is lacking is an active learning paradigm—grounded in principles of cognition—that helps ensure that students learn the functional value of the material by working directly with the content.

Serious gaming, an even more recent approach to training within the active learning paradigm, can be defined 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 [Zyda 2005]. A key difference between computer games and serious games is that the latter uses pedagogy to infuse instruction into the game play experience, thus providing a delivery system for organizational video game instruction and training. Since the 1997 publication of the National Research Council report titled “Modeling and Simulation – Linking Entertainment and Defense,” we have seen several serious games emerge for a variety of domains – America’s Army (http://www.americasarmy.com), SimNavy [Capps et al. 2001], emergency preparedness [Turoff et al. 2006], and many others. Serious games involve activities that educate or instruct, thereby imparting knowledge or skill. It would be of interest to understand the psychology behind computer games with respect to the theories of learning (behavioral, cognitive, and motivation theories). Combining psychology and games offers a framework to developing educational games that promote learning while maintaining high motivation of the players [Siang and Rao 2003].

Computer games provide a good environment for learning. In this paper, we describe cognitive principles for effective learning and how they can be applied to serious gaming. We examine one serious game entitled “CyberCIEGE”, a hands-on virtual laboratory that provides cyber security training within a game-based environment. We depict how cognitive principles can be applied to improve the training effectiveness in this serious game. We conclude this paper with recommendations for gaming educators.

2. COGNITIVE PRINCIPLES FOR EFFECTIVE LEARNING

Research on cognitive processing—how information is stored, retrieved, and represented [e.g., Atkinson and Shiffrin 1968; Tulving and Donaldson 1972; Lindsay and Norman

1977]—points to the importance of helping students develop well-connected knowledge structures. When the knowledge structure for a topic is large and well-connected, new information is more readily acquired; the richness of connections facilitates information retrieval. We tend to organize and categorize new information in terms of what we already know (i.e., our knowledge about the world, or semantic memory). Because information that ties in easily with semantic memories is easier to understand and to remember, presentation of new material in training situations should seek to tap into the learner's existing semantic knowledge structures. Showing how the new information or procedures relate to one's experiences—the "real world"—will facilitate this classification/memory storage process and improve retrieval of the information.

Cognitive theory holds that human memory comprises a very limited working memory [Miller 1956], and effectively an unlimited long-term memory [Atkinson & Shiffrin 1968]. Associative processes and organizational processes play an important role in learning and memory. It is well known that humans exploit relationships among items being memorized, and that material being recalled tends to reflect these relationships regardless of whether or not the material was organized when presented [Anderson and Bower 1973]. Knowledge can also be viewed as schemas representing relationships among facts and concepts; knowledge structures contain schemas that may vary in their degree of automaticity [Kotovsky et al. 1985]. Schemas allow many elements of knowledge to be treated as a single element in working memory, which reduces demands on working memory compared to controlled, conscious processing that requires higher cognitive loads [Schneider and Shiffrin 1977; Shiffrin and Schneider 1977].

If a learner has acquired appropriate automated schemas, cognitive load will be low; but if the material has not become organized into structured schemas, then cognitive load will be high, as the many elements that comprise the material must be considered discrete. In short, learners have difficulty with instruction unless they are already fairly acquainted with the material—which leads to a paradox [Carroll 1987]: "To learn, [users] must interact meaningfully with the system, but to interact with the system, they must first learn." (p. 77). Research on "minimalist training" aimed at addressing this paradox suggests that an effective approach is to encourage learners to work immediately on meaningful, realistic tasks; to reduce the amount of reading and other passive activity; to use prior knowledge to advantage; and to help make errors less traumatic and pedagogically productive [Carroll 1987; 1990].

Interactive experiences in applying what has been learned should be, to the greatest extent possible, presented in realistic contexts. When carefully designed, quizzes and interactive exercises can provide unique and valuable opportunities for learning through exploration and discovery. The key to this enhanced type of performance testing is incorporating student-centered activities involving manipulation of objects to solve problems (i.e., working directly with the content rather than answering factual questions that only require rote learning). Problem-centered training helps to instill learning experiences that are intrinsically rewarding, relevant, and enjoyable for the student [Wilson et al. 1993]. Engaging learners in problem-solving activities, rather than passively digesting course content, not only increases motivation but also compels them to think about, organize, and use the information in ways that encourage active construction of meaning, help build lasting memories, and deepen understanding of the material. A similar philosophy is espoused by constructionist learning theory, which argues that learning through designing and constructing personally meaningful projects is better than learning by being told [e.g., Bruckman 1998; Papert 1991].

These cognitive principles lead to the following active learning instructional design guidelines that have guided the development approach in a variety of our e-Learning and training applications:

- *Stimulate semantic knowledge.* Relate material to the learner's experiences and existing semantic knowledge structures to facilitate learning and recall of the information.
- *Manage the learner's cognitive load.* Organize material into small chunks, and build up gradually from simple to complex concepts.
- *Immerse the learner in problem-centered activities.* Provide opportunities for learners to work immediately on meaningful, realistic tasks.
- *Emphasize interactive experiences.* Develop problem-centered activities that require manipulation of objects to encourage active construction/processing of training material to help build lasting memories and deepen understanding.
- *Engage the learner*. Devise learning scenarios that maintain the performance of learners in a "narrow zone" between too easy and too difficult.

There is a relationship between the dimensions of active-passive learning and level of engagement. Generally, as we design training paradigms that require the learner to take a more active role, the more engaged the learner becomes in the training process. A development challenge is that the more active paradigms are more difficult and expensive to build. Figure 1 [from Greitzer 2005] illustrates different levels of engagement (increasing from 0 through 4) that provides a convenient context for understanding the relationships among different approaches to computer-based training ranging from rudimentary case-based training up to game-based learning. Level 0 represents traditional, linear training paradigms that place the learner in a rigid, passive training environment. Level 1 represents an advancement that employs simple scenarios or interactive examples that demonstrate or require the learner to work through a problem that is tied to a learning objective. This level is characterized by narrow, highly-focused problems that stand alone, i.e., it presents independent problems. This independence is

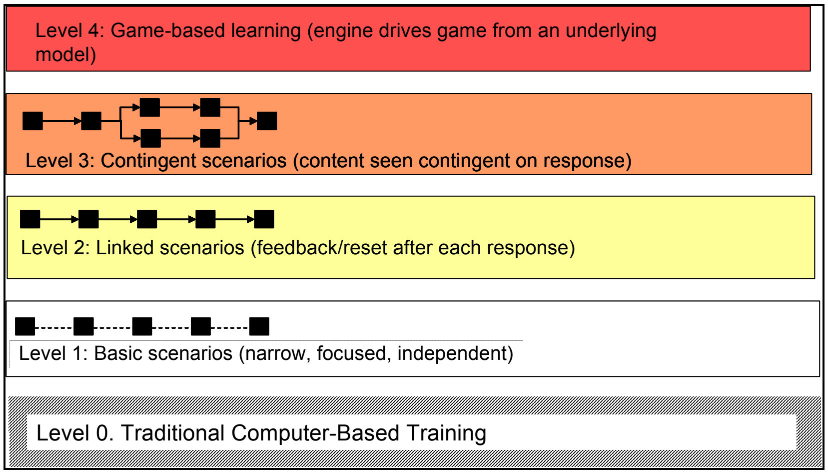

Fig. 1. Computer-based training approaches vary in levels of engagement.

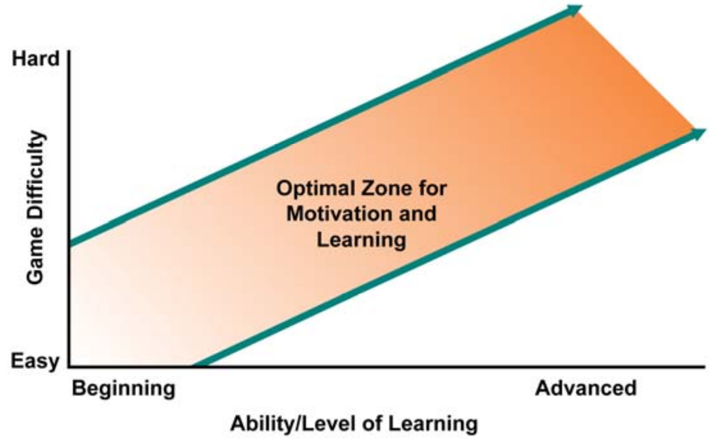

Fig. 2. Game flow and difficulty should be engineered to maintain the learner's motivation.

both an advantage and a disadvantage—it is easier to construct and to manage/assess performance, but it lacks the operational relevance of more realistic, linked scenarios. Level 2 is a step-up in sophistication by providing linked scenarios that present a more realistic problem, but to manage the problem of supporting a potentially unlimited number of "paths" that a learner might take based on choices/performance through the steps of the scenario, the system provides feedback after critical steps and thereby "resets" the problem after each step. In this way, the learner cannot stray too far afield. Greitzer [2002] and Greitzer et al. [2003] report on an e-Learning application developed using this paradigm. Level 3 is a more interactive training approach that allows for a limited amount of "branching" accommodating different choices or performance by the learner. Level 4 largely eliminates constraints on branching by employing a game-based paradigm with richer scenarios that are managed/controlled by a game engine.

As Quinn [2005] emphasizes, learning should be "hard fun." Kuchar et al. [2006] apply this philosophy by endeavoring to construct learning experiences that maintain a high level of motivation and challenge the learner, without going too far and frustrating the learner with performance requirements that are too difficult (see Figure 2).

3. GAMING

Games differ from most applications we use in their use of visual, textual, and auditory channels for feedback, challenges, goal indicators, and other components. Few games rely on manual instructions or courses to get a player involved in a game. Thus, we find computer games engaging through rich visuals that entice players into fantasy worlds. Green and Bavelier [2003] have grabbed national attention for suggesting that playing "action" video and computer games has the positive effect of enhancing students' visual selective attention. Computer games motivate via fun, challenge, and instant feedback within an environment that creates an immersive experience. As noted by Prensky (2003), a *sine qua non* of successful learning is motivation – a motivated learner cannot be stopped. There is also a social context – some games can be played against real people over the internet. Games can handle large amounts of content that can be easily updated and customized by players. During game play, players can participate in many different roles (e.g., decision maker, team leader, thinker, and team player). Games engage players in experimenting with different ways of learning and thinking – finding new ways to tackle the game.

So it seems that games are a viable medium for learning. Players learn to digest information from many sources and make decisions quickly; to deduce a game's rules from playing rather than by being told; to create strategies for overcoming obstacles; and to understand complex systems through experimentation. The combinations of video, audio, and text are useful in accommodating different learning styles, thereby promoting confidence and encouraging multi-modal literacy. Games enable engagement in activities otherwise too costly to resource or too dangerous, difficult, or impractical to implement in the classroom.

The merging of learning and gaming brings with it a few challenges. As noted in Prensky [2005], there are two types of games: mini (trivial) and complex. Mini-games are games that take less than an hour to complete, treat only one subject, puzzle, or game play type in a small way. Complex games are games that take more than 10 hours to complete, provide a sophisticated mixture of difficult challenges that typically intertwine and support each other. Complex games often have one or several mini-games embedded within them for specific learning purposes. What makes a complex game different from a mini-game is that a complex game requires a player to learn a wide variety of often new and difficult skills and strategies, and to master these skills and strategies by advancing through dozens of ever-harder "levels." Doing this often requires both outside research and collaboration with others while playing.

A number of features distinguish complex games that entice people to play for hours at a time:

- *Leveling-Up.* One of the most important features is improving through "leveling-up." Leveling-up literally means getting to the end of one level and starting another. This validation of improvement provides reinforcement for the learner. Game players love the feeling of "getting better" at something – especially achieving mastery over something difficult and complex.
- *Adaptability.* Effective complex games incorporate the strategy of adaptability. A complex game adapts to each players skills and abilities through highly advanced artificial intelligence programs that sense just how a player is doing, and then change the game slightly whenever the player leaves the "flow zone" (the pleasure from getting better or mastery at successively higher levels as the feeling of "flow" or of being in a "flow state") in order to move that player back into it. Modern games adapt automatically to every player, individually. A game that adjusts the difficulty precisely to the player's specific abilities is a very powerful attraction.
- *Clear and Worthwhile Goals*. A third feature of complex games is having worthwhile goals. These are goals that players really want to achieve. Making sure the player's goals are clear and compelling is a major piece of game design. Goals are provided on several levels, including very short-term goals (e.g., get to place X and do Y), medium-term goals (e.g., finish a level), and long-term goals (e.g., defeat the main villain or earn a special ability). An extension of having worthwhile goals is also having a number of choices leading to a satisfying conclusion. Players may find a game frustrating or too simplistic if there is only one way to solve a problem.
- *Interaction with Other Players.* The ability to cooperate and interact with other players (either simulated or real) can determine the kind of experience an

individual will have when playing the game. For example, if one player is interacting with other real players, the player needs to learn how to properly interact and communicate with these players in order to achieve success in the game.

- *Shared Experiences*. A final feature of complex games is the ability to create and share one's experiences with others. This creation and sharing mechanism allows "expert" players to create more challenging levels for other players, incorporating features that they liked in previous levels or incorporating features that were not present in any levels that they wish there were.

4. APPLYING THEORY TO PRACTICE: CYBERCIEGE

CyberCIEGE, a hands-on virtual laboratory developed by the U.S. Naval Postgraduate School, provides cyber security training within a game-based environment (see Figure 3). CyberCIEGE enhances information assurance education and training through the use of computer gaming techniques. In the CyberCIEGE virtual world, users spend virtual money to operate and defend their networks, and they see the consequences of their choices. The CyberCIEGE training application covers the significant aspects of network management and defense. The concepts being taught in CyberCIEGE are security concepts that encompass different aspects of a multi-layer communication network, ranging from physical security to software security on standalone to completely networked machines. Users purchase and configure workstations, servers, operating systems, applications, and network devices. They make tradeoffs as they struggle to maintain the ideal balance between budget, productivity, and security. It employs beginning scenarios as well as more complex, longer scenarios that are presented in a series of stages that require the learner to protect increasingly valuable corporate assets against escalating attacks.

Fig. 3. Screenshot of CyberCIEGE (http://cisr.nps.navy.mil/cyberciege).

As part of a project aimed at assessing the usability and effectiveness of CyberCIEGE, we conducted several studies employing both heuristic evaluations [e.g., Nielsen 1994] by human factors experts and usability studies with representative users. The initial study that focused on user interface design issues [Roberts et al. 2006] identified several dozen usability and human-computer interface design issues and briefly discussed some training effectiveness issues that appeared to impede learning, including a lack of feedback and an uneven distribution of difficulty across scenarios. A follow-up heuristic assessment was performed to more clearly define the learning effectiveness issues, provide a detailed assessment of the application from this perspective, and suggest recommendations for improvement [Kuchar et al. 2006]. The approach in examining learning effectiveness issues was to take into account current practice and research in serious gaming as well as cognitive science implications for enhancing training effectiveness in a serious gaming context. In the next section, we describe the findings of the evaluation based on cognitive/learning principles; and in the following section we describe aspects of the assessment from a serious gaming perspective.

4.1 Summary of Usability and Training Effectiveness Assessment

In the usability study, ten staff volunteers at the Pacific Northwest National Laboratory (PNNL) participated in a full-day assessment in which users received a small amount of introductory training and then played the game in several scenarios. After a half-day of working individually with CyberCIEGE, staff were allowed to work together and think aloud while playing different scenarios. Participants were free to write down comments at any time during the study; and at the end of the day a discussion/focus group was held to obtain additional comments. Participants were asked to discuss their feelings about how much they were able to learn through playing the game; unfortunately, there was no opportunity to conduct a more formal evaluation, such as administering pre-tests and post-tests to measure performance improvement.

The subjective assessments and comments relating to training effectiveness revealed that lack of feedback is a major barrier to learning in this application. Participants indicated that they needed more direct feedback about the correct or most efficient methods for accomplishing a goal: by playing the game and eventually winning, users may not always be able to distinguish between what actions were actually necessary versus actions that were taken that didn't have an effect on states or outcomes. This problem is not unique to CyberCIEGE, but rather is a challenge for all types of interactive instruction, and particularly for exploratory and game-based approaches. A growing number of books and resources exist on more behavioral-based approaches to designing and building game-based learning applications [e.g., Quinn 2005].

A second finding was that the current scenarios in CyberCIEGE were either very simple to solve (e.g., one button change or answering a simple question) or extremely complicated (e.g., hire IT people, buy computers for 20 employees, manage all software/hardware, etc). This is shown in Figure 4, which shows the distribution of difficulty across 15 different projects/scenarios that were available for study at the time of the evaluation. We operationally defined difficulty, in this context, in terms of the number of conditions that the learner was required to set when solving the problem. The actual number of such conditions varied from 1, in the simplest scenario ("Training Macros") to 46, in a more complex scenario ("Area 91"). We classified difficulty using three 'bins' where "Easy" was operationally defined as 0-5 conditions; "Medium" was 6-19 conditions; and "Hard" was 20 and more. As can be seen in the figure, most of the scenarios are in the "Hard" category.

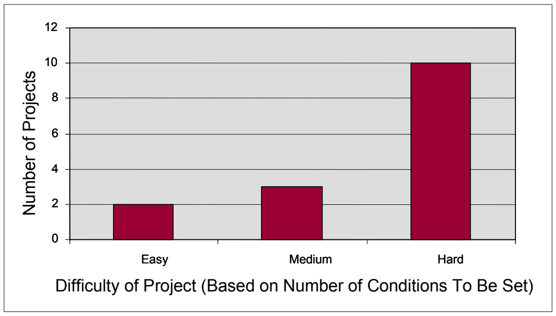

Fig. 4. Frequency Distribution for Relative level of Difficulty in the CyberCIEGE Projects.

4.2 Applying Cognitive Principles

Major conclusions from the modest study reported in the previous section were that insufficient feedback and confusion about how to use the CyberCIEGE controls/user interface elements to accomplish tasks made it difficult for learners to easily recognize what concepts are being taught in some of the scenarios; this may have led to decreased motivation and increased frustration with the game. In this section, we offer some suggestions based on cognitive learning principles for addressing these deficiencies.

4.2.1 Scenario Difficulty. A major focus of the study was on the difficulty of scenarios and the distribution of difficulty across scenarios, in an effort to devise approaches and solutions for defining and organizing scenarios for more effective learning. Experiential/discovery-based approaches to computer-based training (which includes game-based learning) impose a higher cognitive load on the learner [e.g., Clark 1998; Greitzer 2002; Greitzer et al. 2005]. To address this training effectiveness issue, it has been suggested to divide more complex tasks into simpler ones, and to build from simple to complex problems or scenarios as learning progresses [e.g., Greitzer 2002; Greitzer et al. 2005]. This was indeed the recommendation of the Roberts et al. [2006] report: i.e., divide more complicated tasks into simpler ones and to build from mini to complex projects as learning progresses.

We used this approach to address the scenario difficulty issue by creating more scenarios that focus on simpler, more specific topics for less-experienced learners, and then building upon these simple scenarios to create more complex and realistic scenarios. This is done by starting with scenarios that are almost completely solved—perhaps with only one problem to fix. A single, completed scenario might be cloned multiple times and then “tweaked” by removing a critical feature (e.g., remove the policy to not open e-mail attachments from unknown sources). In this way, learners will be able to focus on very specific learning objectives without having to perform a series of overwhelming tasks to purchase equipment, set up equipment, hire IT support, set policies, etc. By selectively “tuning” clones of scenarios to meet specific learning objectives, the required performance and necessary feedback will be much more obvious to the learner. Successive games with modified versions of the scenario can gradually teach the learner about specific concepts. As the learner acquires and demonstrates more advanced skills and knowledge, scenarios may be assigned that have more features. An “integrative” test of knowledge and skills would be to present the raw scenario that requires all of the necessary purchases, hires, policies, etc. Essentially, we are advocating that the progression be structured in exactly the opposite "direction" from the current game/scenario configuration.

To apply this approach on a significant scale, a more structured method for defining and managing complexity of the training scenarios is required. We developed a conceptualization of a layered structure to accommodate the range of difficulty and associated learning objectives for existing and potential scenarios. This layering approach for structuring learning material allows a CyberCIEGE player to gradually learn different aspects of security that increase in complexity. After moving through the successive layers of complexity, learners may be given additional experience with more diverse scenarios that mix-and-match the different layers of security to aid in further developing skill and knowledge.

4.2.2 Layered Training Concept. The layered training concept for serious game design uses the principle of building complexity by systematically structuring the gaming scenarios to meet increasingly more complex learning objectives. For the CyberCIEGE training application, after considering the set of existing and potential scenarios (called projects), we developed a conceptualization of a layered structure to accommodate the range of potential scenarios and associated learning objectives. This is depicted in Figure 5, which illustrates how projects may be defined for the cyber security application by creating an expanding/increasing set of problems or challenges associated with different layers. The focus of the learning objectives/scenarios in the inner-most layer (Layer 1) is to define and learn about security with only a standalone machine. Security issues would contain physical security, passwords, external media (such as CDs, DVDs, thumb drives, external drives, etc), virus protection, training, etc.

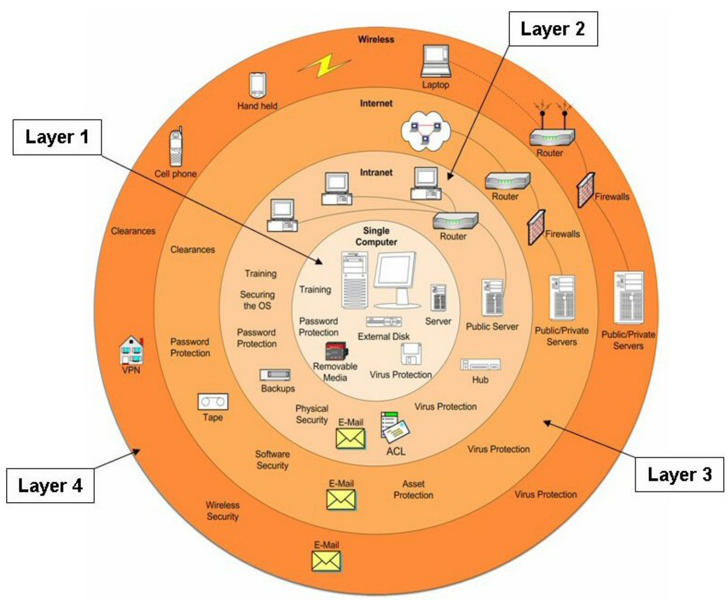

Fig. 5. Visual depiction of our layered training concept.

Layer 2 adds complexity by requiring that the learner deals with protecting computers on an internal network (intranet). This layer of security would cover issues such as password protection, secure operating systems, hubs, routers, physical security of computers or servers, asset protection with ACL, back-ups, internal e-mail, public (internal) servers, training, etc.

Layer 3 deals with protecting computers that are both internally connected (intranet) and externally connected to the Internet. This layer of complexity would cover issues such as asset protection, routers, firewalls, servers, viruses (Trojan horse, etc), software security (secure third-party software), clearance, public and private servers, etc.

Layer 4 deals with allowing access to the intranet from an outside location, such as security with VPN. This layer would also include security clearances, wireless devices such as laptops, blackberries, and other instruments that can connect to the company network from different locations.

This layering approach for structuring learning material allows a CyberCIEGE learner to gradually learn different aspects of security that increase in complexity. After moving through the successive layers of complexity, learners may be given additional experience with more diverse scenarios that mix-and-match the different layers of security to aid in further developing skill and knowledge. The point of the layered approach is to disclose information in a more gradual and systematic manner to allow a learner to understand the different layers of security that exists. This form of progressive training stresses learning basic concepts first, including how to play CyberCIEGE, which sets the stage for covering more advanced concepts later.

4.2.3 Motivation. To address a potential problem with learner frustration and motivation, further consideration of motivational factors should be fruitful in enhancing the training effectiveness of CyberCIEGE; motivation is the key to learning and gaming. Motivation theory is central when discussing theories of learning. Figure 6 depicts a hierarchy of players' needs that Siang et al. [2003] proposed, based on Maslow's original hierarchy of needs [Maslow 1970]. By understanding a player's needs, game designers can direct the player's motivation to learn through a gaming environment. As with Maslow's hierarchy, the lower levels need to be fulfilled before any of the higher levels in the pyramid.

At the bottom level, a player needs information to understand the basic rules of the game. This is the fundamental need since no player can be motivated to play without knowing the basic rules. Once the rules need is satisfied, a player moves to a safety need: to meet this need, a player needs helping information to stay in the game long enough to win and avoid being knocked out; i.e., a player needs to feel safe and secure. The third level is a belongingness need in which a player must feel comfortable with the game and eventually achieves the game's goal (or at least to believe that it is possible to achieve). After a player knows that winning is possible, there is a need to feel great when playing the game—a feeling of esteem. A player needs to feel in control over the game. At the next level, a player needs to understand and know more about the game, such as different strategies, hidden items, etc. A player starts to expect something more challenging. The sixth level is an aesthetic need, in which good graphics, visual effects, appropriate music, sound effects, etc are important to a player. The top level is a stage in which the player feels able to do anything within the game rules and constraints (attaining a form of perfection in the virtual world). A similar interpretation of Maslow's self-actualization hierarchy has been applied by Hancock et al. [2005] as a hierarchy of ergonomics and hedonomic needs: In this interpretation, safety, the prevention of pain, forms the

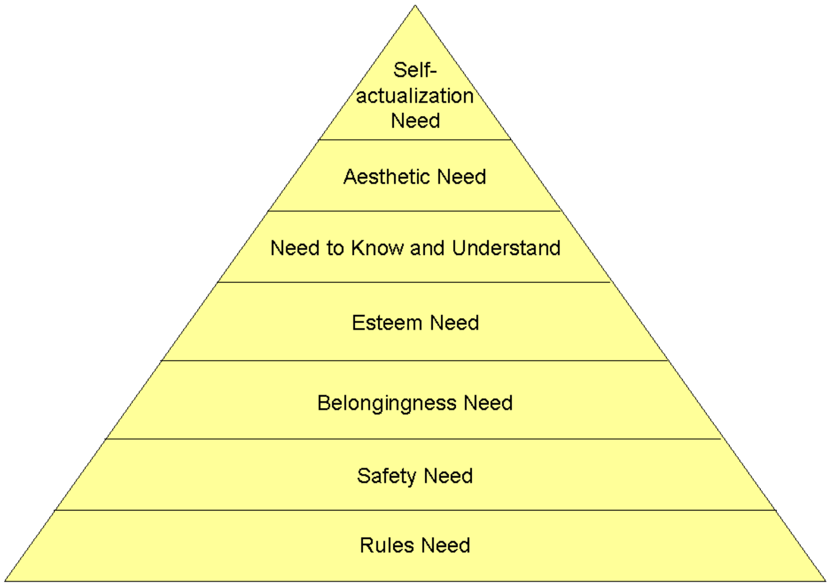

Fig. 6. Hierarchy of the players' needs, adapted from Siang et al. [2003].

foundation of the pyramid; next comes functionality, the promulgation of process; then usability, the priority of preference (the transition from ergonomics to hedonomics begins at the usability layer); the next layer is pleasurable experience; and the apex of the pyramid comprises individuation and personal perfection.

Training game designers should be able to derive some useful principles of game design from this hierarchy of needs. It must be remembered that if a player fails to understand the rules of a game in the first few minutes, a player will simply walk away; or if this is a mandatory training program, the player may just "tune out" and do the minimum necessary to satisfy the requirement.

4.3 APPLYING GAMING PRINCIPLES

Complex games are the games that inspire children and adults to sit in front of a computer screen for hours playing and learning. We have described several features that are common to complex games: leveling-up; adaptability; clear and worthwhile goals; interaction with other players; and shared experiences. Although we have not yet had an opportunity to apply these ideas to CyberCIEGE, we believe that they can be profitably incorporated into the CyberCIEGE gaming environment. In this section, we describe some ways that these principles may be applied to enhance the learning effectiveness of the game.

Leveling-up is one of the easiest features that can be incorporated into CyberCIEGE. A scenario builder can create phases during a project and save these projects into campaigns. The key here is for learners to "feel better" at something – maybe a complex task or understanding a concept. Instead of the scenarios in a campaign being disjoint, a scenario builder can build off of the previous scenario, increasing the "layer" of learning while reinforcing the concepts being taught. During these scenarios, a learner can solve many mini games and puzzles, increasing the bonuses and being promoted to different levels of IT. For example, at the beginning of a scenario, the learner starts-off as the junior IT staff member and can then progress to a manager, supervisor, etc., by having more/different responsibilities, with more IT people to manage.[1]

Adaptability is a feature of complex games that presents a longer-term research and development vision for CyberCIEGE. This feature increases the complexity of both playing and creating scenarios for CyberCIEGE. The ability for the game to adapt to a learner's skill and ability requires more artificial intelligence than is currently incorporated into the game. A near-term adaptability goal for CyberCIEGE is the ability for learners to seek help or guidance if they are unable to progress beyond a particular point in the game. For example, if we keep track of the number of "restarts" of a particular scenario and save the learner's path each time, we can determine what the learner is doing wrong and provide either feedback or guidance after a specified number of attempts through the project. If the learner is very good at accomplishing the tasks, we may want to have some "tricks" to further challenge the able learner. Again, we can check the progress (length of running scenario) against some initial values. These small but doable tweaks could provide not only adaptability, but also a solution to the frustration that some novice learners experience when trying to complete a scenario for the "fifteenth" time, and keep dying by the "Trojan Horse" no matter what they feel that they do.

Worthwhile goals are already incorporated into CyberCIEGE – protect and keep the network alive. These goals could be improved with the introduction of a good villain and giving a villain a face or presence in the game. Currently, the villain is just some text that floats up from a computer or appears on the gaming screen. It comes out of nowhere and is frustrating. If we had a good villain and could see that he was already thinking of attacking, we could brace or be proud when he cannot get the network down. This would give good feedback to the learner. Also, the introduction of decisions and having multiple paths to a solution would provide better opportunities at worthwhile goals.

The ability to cooperate and interact with other players is a long-term goal that we may consider for CyberCIEGE. Multiplayer games are difficult for scenario builders to create and manage. There are many variables in creating good multi-player games:

- Bandwidth and latency. Do as much record-keeping and processing on the client side. Don't send information to the server and back unless it is absolutely necessary.
- Keep the game level simple. A level can have a simple layout yet still offer a great depth of game play.
- Create stories for an adequate number of players. Do not assume that there will only be four players at a time. The stories need to scale well based on the number of players.
- Keep physics in mind when designing an interactive game. Even simple layouts can create many problems.
- Be aware of collision between players and environment. When creating players and their environment, creating small pieces of parts may provide some problems with the gaming engine.
- Be creative.

For more insights, several good books are available on the topic of designing online games, such as *Developer's Guide to Multiplayer Games* [Mulholland and Hakala 2002],

[1] This notion was implemented in an online training application developed at PNNL for training of security inquiry officials. The training application is described in Greitzer et al. (2005); and Greitzer (2005; 2006).

Massively Multiplayer Game Development [Alexander 2005], and *Mud Game Programming* [Penton 2004].

5. SUMMARY AND CONCLUSIONS

In this paper we examined cognitive/instructional design principles and serious gaming learning effectiveness issues that may explain why people spend hours of their time playing computer games. With this background, we reported our assessment of the relative complexity of a game-based training environment for cyber security education and training (CyberCIEGE) and possible enhancements based on this perspective. We examined the current CyberCIEGE scenarios with respect to gaming, and we proposed a layered approach to CyberCIEGE training with several examples of scenarios. We examined how different aspects of gaming technology could be enhanced in CyberCIEGE.

Serious games are more than just story, art, and software – they involve pedagogy. In creating educational classes to teach computer learning, educators need to develop course content that covers this multidisciplinary area. Courses on storytelling, interface design, gaming engines and tools, and learning theory need to be mandatory for serious game developers. Adopting a cognitive approach to game development will give developers the tools to create theories and methods for [Zyda 2005]:

- Modeling and simulating computer characters, story, and human emotions.
- Analyzing large-scale game play.
- Innovating new game genres and play styles.
- Integrating pedagogy with story in the interactive game medium.

Pedagogy and story integration involve determining theories and developing practices for inserting learning opportunities into a story, such that participants find the story immersive and entertaining because the embedded instruction remains subordinate to it. There is a need to create a science of games – a scientific and engineering method for building games and understanding and analyzing game play, not merely as a means of producing more realistic simulations of the physical world, but focused on pedagogical approaches that provide effective, relevant, and motivating learning experiences.

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