COGNITIVE TASK ANALYSIS: ANALYZING THE COGNITION OF GAMEPLAY & GAME DESIGN

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ABSTRACT

A prior study performed by ADL, which measured the effects of certain video game design features thought to increase cognitive adaptability, brought to light how little is understood of the cognitive elements of video games, even by those who design them, let alone those who wish to study them or utilize them for learning or improving cognitive functioning. It has long been standard practice by instructional designers and those in industrial/organizational psychology to utilize a process known as cognitive task analysis (CTA) in order to analyze the cognitive and behavioral requirements of an expert-level performance of a certain task. They are broadly recognized as an effective tool for cognitive mapping. ADL researchers scoured the existing base of research in industrial/organizational psychology, cognitive psychology, and gaming, as well as consulted with experts in the video game industry, and found that no efforts to apply CTA methods to or cognitively map a video game—identifying and enumerating on features such as implicit and explicit rules and reinforcement, rule and environment shifts, audio and visual cues, behavioral and cognitive requirements of players, and goals, sub-goals, and micro-puzzles—in order to analyze the cognitive effects of its design could be found. It was towards the end of filling these gaps in knowledge about the cognitive makeup of Portal 2, as well as developing a methodology for applying CTA techniques to video games for future research and utilization for learning, that the researchers at the ADL Initiative are undertaking an effort to perform a cognitive task analysis on Portal 2 play. This paper details the novel methods the team has developed, both by adapting traditional CTA methods to analyze the cognitive requirements of gameplay as well as creating techniques to capture the cognitive effects of unique video game design principles, as well as initial findings.

ABOUT THE AUTHORS

Dr. Shane Gallagher is the co-lead for the ADL Next Generation Learner team. Shane received his Ph.D. in Instructional Technology from George Mason University and MA in Educational Technology from the University of New Mexico. He has led research and evaluation projects in learning object content models, simulations, reusable pedagogical models, organizational readiness, and knowledge management. He has been recognized by NASA for his work on assessing the Johnson Space Center on knowledge management readiness by the JSC Chief Knowledge Officer and has accrued customer recognition and awards for thought leadership, innovation, and instructional design. Currently the program director for Serco's support to the ADL Initiative, he authored the chapters "The Development of SCORM" and "The Challenges to SCORM" in *Learning on Demand: ADL and the Future of e-Learning*. Shane is an active consultant in the area of education and interoperability and has taught in public, private, and higher education, also functioning as department and committee chairs.

Shenan Prestwich joined the ADL team in early 2009, and has since been a part of efforts to research and evaluate advanced technology-based/technology-mediated training, as well as the effectiveness and impact of emerging learning technologies and adaptive learning, cognition, and behavior. Shenan holds an undergraduate degree from James Madison University in anthropology and archaeology, and a Masters in writing from Johns Hopkins University. Her research at ADL has explored topics such as leveraging video game design to enhance cognitive adaptability, transfer from simulation training to on-the-job performance and how to foster more effective transfer from simulation training, the effectiveness of computer-based simulation games for learning, and the current landscape of mobile technology use in DoD and the military Services. She has also been involved in efforts to longitudinally track e-learning usage metrics from the LMSs of each of the military Services.

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INTRODUCTION

Adaptability is a metacompetency critically important to the United States Department of Defense and is considered a key component of 21st Century skills by the U.S. Department of Labor (U.S. DoL, 1991) and the U.S. Department of Education (U.S. DoEd, 2012; Partnership for 21st Century Skills, 2008). There is a need for organizations, leaders, and individuals to adapt to an increase in the type and intensity of stressors and ambiguity existing in today's business, political, and defense environments, a need that is not limited by organizational or generational boundaries. ACT21S (Assessment and Teaching of 21st Century Skills) have identified three "ways of thinking" skills as part of defining 21st century skills: creativity and innovation; critical thinking, problem solving, decision making; and learning to learn, metacognition (Binkley et al., 2011). Creativity, problem solving, and metacognition are all crucial cognitive skills facilitating competence in being adaptable.

Training for adaptability and an "adaptive stance" (Grisogono, 2010) have been a longstanding interest of the United States (U.S.) Department of Defense (DoD), commensurate with the rise of asymmetric and irregular warfare. Adaptive stance and adaptability, while an important competency at a performance level, begin on a cognitive level. That is, micro-momentary decisions and cognitive processing (i.e., adaptive cognition) are the basis for adaptable behavior and performance, which in turn comprise adaptability at a human systems level. Therefore, utmost importance must be placed upon understanding and fostering adaptability at its origin: the cognitive level.

To address the exigencies of organizations within military and industry, and the educational outcomes defined as 21st century skills, learning environments need to support the types of activities fostering these skills in a manner that is highly engaging, motivational, leverages generational differences, ubiquitous, easily accessible, and appeals to a variety of learners and age groups. Games and serious games support both generational differences and a varied, ubiquitous set of technological opportunities that can be leveraged for learning (TRADOC, 2010). As such, if games and serious games do indeed have the ability to foster the cognitive adaptability, they could be employed more extensively as components of virtual learning environments.

However, in order to utilize the full capabilities of commercial off-the-shelf computer-based games for training adaptability, the design characteristics that specifically contribute to an increase in cognitive adaptability and which games possess these design characteristics must be identified. Towards this first end, researchers at the Advanced Distributed Learning (ADL) Initiative conducted a study to pinpoint what design characteristics might foster cognitive adaptability in game players and test whether a game possessing these characteristics (Portal 2) produces any change in the cognitive functioning of the players. That study, along with other valuable data, brought to light how little is understood of the cognitive elements of video games, even by those who design them, let alone those who wish to study them or utilize them for learning or improving cognitive functioning. In scouring the existing base of research as well as consulting developers in the video game industry, no efforts to cognitively map a video game—identifying and enumerating on features such as implicit and explicit rules and reinforcement, rule and environment shifts, audio and visual cues, behavioral and cognitive requirements of players, and goals, sub-goals, and micro-puzzles—could be found.

How do you capture the thought process of an expert gamer as they make their way through a game? How do you map out, scientifically, exactly what it takes to conquer a game like Portal 2? It has long been standard practice in industrial/organizational psychology to utilize a process known as cognitive task analysis (CTA) in order to analyze the cognitive and behavioral requirements of an expert-level performance of a certain task. CTAs have been widely

performed in government and industry to creative cognitive maps of workplaces, as well as in education in order to map the cognitive requirements of learning in order to build educational tools and programs. They are broadly recognized as an effective tool for cognitive mapping. But applying CTA methods to video games and the cognition of gameplay itself is virtually unheard of. No precedents for this kind of analysis emerged from the literature on industrial/organizational psychology, cognitive psychology, or gaming. It was towards the end of filling these gaps in knowledge about the cognitive makeup of Portal 2, as well as developing a methodology for applying CTA techniques to video games for future research and utilization for learning, that the researchers at the ADL Initiative are undertaking an effort to perform a cognitive task analysis on Portal 2 play.

COGNITIVE TASK ANALYSIS (CTA)

Cognitive task analysis is a qualitative analysis technique that has traditionally been used by researchers and industry professionals to capture both the behavioral and cognitive processes and activities that go into accomplishing a task at an expert level. This includes decision-making processes, recognizing and responding to critical cues, responding to environmental conditions, utilizing tools, performing smaller sub-tasks, and analyzing and altering one's own performance. It generally consists of a subject matter expert (SME) who has mastered a task at an expert level, performing or describing the procedure of performing the task in question, followed by detailed interviews by the researcher. According to Cooke (1994), there are three broad types of CTA techniques: observations and interviews, process tracing, and conceptual techniques, with a fourth category, formal models (using simulations to model cognitive tasks) added by Wei and Salvendy (2004). In their literature review on CTA methods, Clark, Feldon, van Merrienboer, Yates, and Early (2006) outlined five common phases of performing a CTA within those four broad technique types, which include collecting preliminary knowledge, identifying knowledge representations, applying focused knowledge elicitation methods (sometimes accomplished through applying Klein, Calderwood, and MacGregor's (1989) Critical Decision Method, a semi-structured interview technique based on the idea that expert decision making is largely based on effective and efficient recognition of cue patterns with only a subconscious evaluation of alternatives), analyzing and verifying the data, and preparing the results for publication. In addition to the methodology proposed by Clark et al. (2006), Militello and Hutton (1998) laid forth a technique for CTA known as Applied Cognitive Task Analysis. Applied Cognitive Task Analysis is comprised of three techniques, each designed to map out different aspects of cognitive skill associated with a task: task diagram interview, knowledge audit, and simulation interview (Militello & Hutton, 1998).

CTA AND VIDEO GAMES

Cognitive task analysis has been applied to educational game design in some ways, such as Boyle et al.'s (2012) study which utilized CTA to aid in the design of a digital game to support research and statistics education, and Shute and Kim's (2012) study which included a cognitive task analysis performed on a specific level of the game *World of Goo*, called "Fisty's Bog," in order to pinpoint competency model variables to inform an evidence-centered design model of the game. However, very little cognitive task research has been done on the cognitive and behavioral performances of expert gamers or the cognitive requirements of existing games both within individual levels and tasks, as well as throughout the narrative structure of the game as a whole, and as far as is apparent from the literature, no efforts have been made to employ CTA for the purposes of identifying the presence of specific design tenets within a video game. It was with both these goals in mind, in addition to wanting to develop and implement a rubric for identifying the presence or absence of particular design characteristics thought to improve cognitive adaptability, that a cognitive task analysis on Portal 2, the commercial off-the-shelf video game used in the previously mentioned ADL study, was undertaken. The challenge then became how does one take the principles of industry-focused cognitive task analysis practices and apply them to video games and video game behavior?

Since no precedents for this kind of analysis could be found in industrial/organizational psychology, cognitive psychology, or gaming literature, the ADL team had to develop a protocol for performing a CTA to analyze video game design and video gamer cognition within a particular game. Drawing on established CTA literature as well as a trial-and-error process of piloting the protocol, the team produced a three-part method for analyzing the design and cognitive/behavioral requirements of gameplay.

Part 1: Preliminary Analysis/Lexicon Development

The first phase of a video-game-centered CTA involves building a language and a set of units of analysis with which to talk about and approach the game. As game developers themselves oftentimes only record and release partial or informal access to an official vocabulary to describe game features and granular units within the narrative of the game, it's important that all researchers and expert gamers participating in the CTA agree on a singular lexicon and approach to talking about the game. Oftentimes, parts of this information can be sourced from the game developers themselves, and it's useful to start with any information available from the developers as a base to build upon. In the case of ADL's CTA efforts, this effort was two-fold.

First, upon learning that no official documentation of the cognitive decision-tree or physical map of the game was available, the team utilized a program released by Valve, the developers of Portal 2, in which users can build their own levels in the game. The program provides the user with a set of "building blocks," so to speak, of tools, environmental features, and obstacles featured in the game with which to build a level. The researchers used the game features and the names provided for them by the developers in this program as a basis for creating a vocabulary with which to talk about the game. The named features provided the basic vocabulary, which was then expanded upon using input from expert gamers as well as the researcher's own experiences playing through and familiarizing themselves with the game.

Second, a game structure analysis was performed to break the game down into measurable units based on the narrative structure of the game. In this case, the researchers decided to follow the game's structuring of the narrative into chapters and, within those chapters, levels, and also decided it was best to add "rooms" as a unit of analysis, as a significant portion of levels consist of several smaller rooms the player must move between, often completing puzzles in each one. Chapters and levels were the main units of analysis, with each level within a chapter having a separate CTA performed on it in service of the overarching cognitive task analysis, but rooms were an important unit to make note of and refer to within each level.

Part 2: Focused Knowledge Elicitation

In this phase, a player (either expert or novice, depending on the research goals, as each will have different cognitive experiences) plays through the game, one level and chapter (or whatever the smallest unit of game analysis is, as determined in phase 1) at a time. Before each level, the researcher reads the following instructions:

> *Please play through this level, completing the necessary steps to achieve the final objective. As you do, try to speak aloud as much as possible, narrating both your thought process (including what decisions you are making and what options you are considering) and the sequences of actions you take as you take them.*
>
> *As you play, please survey the areas you are in and describe your expectations in terms of how you will have to interact with the room in order to achieve your objective.*

The player then plays through the level, attempting to follow the given instructions. During this part, the administrator should prompt subject to fill in gaps in their talking aloud, asking about specific decision points or actions that the subject doesn't seem to have verbally articulated. It is key that the player's gameplay at this point is recorded through video capture software such as FRAPS, or another program(s) that records both what is on the computer screen in real-time as well as the audio of what the player is saying as he or she plays. This is critical as much of the analysis of the gameplay and player cognition will be done in retrospect via discussion between the player and the researcher, and it is helpful to have a recording of the gameplay to reference as this probing and analysis takes place.

After each level, gameplay is stopped and the researcher saves the FRAPS (or other video computer record) for further review. It is recommended that further audio recordings be made of the post-gameplay analysis, so at that point, some form of audio recording is begun. The analysis of the gameplay then commences; in the case of ADL's CTA efforts, this was done in two parts: one, an analysis of the cognitive and manual requirements of each level in an attempt to create a cognitive map and decision matrix of each level, and two, a rubric to identify the presence or absence of certain design features relative to our study on video game design and cognitive adaptability. The latter is something that can be excluded or altered to better fit with the particular research goals.

Cognitive Map/Decision Matrix

Replaying the recording of the gameplay as much as is necessary to extract the information needed, the game player and the researcher then explore the experience of completing the previous level through the lens of the following categories:

- **Final Objective:** What, in the player's estimation, is the overarching goal to be achieved in this level? What do they feel signifies the end and/or successful completion of the level?
- **Mechanical Steps:** What steps, manually and/or behaviorally, did the player have to perform in order to complete the level and achieve its final objective? This can include, in the case of Portal 2, for example, steps like walking down a hallway, shooting a portal, pressing a button, moving an object, etc. Note: this does not necessarily mean what is the most efficient set of steps or the most thorough set of steps, but the steps that were necessary for that particular player to achieve their goal that particular time.
- **Cognitive Steps:** What steps, cognitively, did the player have to go through in order to complete the level and achieve its final objective? This can include, in the case of Portal 2, for example, steps like taking note of visual and audio cues, making decisions, inferring or deducing things from events or information drawn from the game environment, etc. Again, as with the mechanical steps, these are not universal, but particular to the player and the gameplay.
- **Audio and Visual Cues:** What audio or visual cues need to be processed in order to inform the steps the player takes to complete the level?
- **Micro-Puzzles:** What smaller puzzles needed to be solved in order to achieve the larger puzzle of the overarching goal? It's important to note that the difference between a micro-puzzle and a mere obstacle in the game is whether or not it presents a problem to the gamer. Nothing becomes a puzzle until it becomes a problem. For instance, in Portal 2, if the gamer finds themselves trapped in a room in which they know immediately they will need to use portals to escape from, it is not a micro-puzzle, as they know what needs to be done, with what tools, and how to use those tools. If, on the other hand, they encounter a tool they have never used before and need to induce how to use it in order to solve a problem, that object's function is a puzzle.
- **Affordances:** What objects, tools, and environmental features must the player interact with in order to achieve the final goal with are present in this level?
- **Prerequisite Knowledge:** What knowledge obtained prior to this level was necessary to complete this level and achieve its overarching goals?
- **Requisite Knowledge:** What new knowledge needed to be induced or deduced in this level in order to complete it and achieve its overarching goals?
- **Sub-Goals:** What smaller goals arose and needed to be achieved in service of achieving the overarching goal of the level?

Design Rubric

The design rubric portion of the data gathering during cognitive task analysis is designed to work in concert with the cognitive map/decision matrix information to pinpoint the presence or absence of design features of particular importance to the goals of the individual researchers or project(s). In the case of ADL's cognitive task analysis efforts, the design rubric was centered on identifying the five design characteristics—drawn from research in the fields of clinical psychology and learning theory—posited in an earlier study to enhance cognitive adaptability. These five design characteristics are implicit rule sets; implicit shifting of rules; dynamic, shifting environments; some degree of open-endedness in gameplay (though no game will ever be fully open-ended, as the very definition of a "game" requires that there be rules, and thus some degree of constriction to the player's actions), and implicit reinforcement for individual choices and actions in the service of achieving a final goal. There are a multitude of approaches to creating a design rubric, but for the purposes of studying Portal 2 and its effects on cognitive adaptability, the following design rubric was created:

Table 1. Design Rubric for Cognitive Task Analysis of Portal 2

Features 1 & 2: Implicit Rule Sets, Implicit Shifting of Rules

Rules	**Description**	**Implicit or Explicit?**	**New or Altered Rule, or Carried Over from Previous Level?**	**<--If new, indicative of environmental change?**
Constituative				
Operational				
Conduct				

1. Constituative: Abstract, core mathematical rules of a game. Contain essential game logic, though don't explicitly indicate how players enact the rules or engage with the game. Rules that govern the world of the game (like how the real world follows the laws of physics, gravity, etc.), but don't specifically dictate player actions.
2. Operational: Rules of play that players follow when they are playing a game. Usually the kind written out in instructions or rulebooks for the game. Usually explicit.
3. Conduct: Unwritten rules of etiquette and behavior that go unstated in gameplay (i.e., rules of sportsmanship, etc.)

Feature 3: Dynamic, Shifting Environments

Environmental Changes From Task Immediately Prior (please list)	**Result of or cause of rule change? (Y/N)**	**Pure surface/environmental change with no bearing on the rules (constituative, operational, conduct)? (Y/N)***

*Such rules may change player interaction with environment or course of action taken, but three fundamental rule sets listed above remain the same from previous task.

Feature 4: Implicit Reinforcement for Individual Actions to Achieve a Goal

Initial Expectations	**How Experience Differed from and/or Challenged Expectations**	**Explicit or Implicit Reinforcement?**

Feature 5: Open-Ended Gameplay

Ways in Which Gameplay Was Open-Ended	**Ways in Which Gameplay Was Constrained**

After each level, as the player and researcher review the recording of the gameplay together and the gamer is probed for more insight into their behavior and cognition in the game, the researcher uses the design rubric as a starting point for conversation about the experience of gameplay. The researcher first asks the player to list any constituative (abstract rules and logic that govern the world of the game, but don't necessarily dictate player actions or engagement, e.g., gravity, the functions of tools and objects, player abilities within the game to run or jump, etc.), operational (rules of play, usually the kind written out in rulebooks or instructions, for instance, how to move through the game and interact with objects using the keyboard and mouse), and conduct rules (unwritten rules of etiquette and behavior, which come more into play with two-player games than one-player) which were perceived to be present in the level. The researcher can use this as a basis of conversation in which to contribute their own observations and questions about the rules of the level. For every rule that is determined to have been present, the researcher and player then determine together whether the rule was explicitly given or explained to the player or whether it had to be implicitly discovered, as well as whether it was a rule that was carried over from a previous level or levels, or whether it was a new or altered rule. If it was a new or altered rule, the player and researcher then determine if it was the result or cause of an environmental change, or if the rules changed independently of the game's environment.

They then go on to discuss any possible environmental features in the level that indicate a change from the environment of the previous levels (or any levels preceding it). For each environmental feature listed, the researcher and player together then determine whether each was a pure surface environmental change, or whether it was indicative of or the cause of any of the rule changes listed in the first section of the rubric.

In the next section, the researcher and player then go through the FRAPS recordings again, observing the player's vocalized expectations about each area they encountered, with the player supplementing any gaps in which they had certain expectations but did not specifically vocalize them. The player then elaborates on whether those expectations were confirmed or challenged, and what sort of feedback was given to them (implicit feedback, such as a visual or audio cue or a shift in the environment, or explicit feedback, such as a character saying "Good job!") to reinforce the correctness or incorrectness of their expectations.

Finally, the researcher asks the player to describe what elements of the level felt open-ended to them (for example, freedom of movement, lack of a time limit, etc.) and in what ways their gameplay felt constrained at all (for example, only one solution to a puzzle, limited space in which to explore, etc.).

INITIAL FINDINGS

Analyses of the qualitative data collected for each level of Portal 2 that was examined in CTA process is still ongoing. Eventually, the team hopes to create a cohesive, overarching picture of the cognitive requirements of Portal 2 and its effects on player cognition, as well as map out the critical cognitive and mechanical paths to successful game completion. However, already some initial findings on the presence of the five design characteristics of interest vis-à-vis cognitive adaptability have emerged. As can be seen in Figures 1-3 and Table 2 below, of the levels sampled for observation through the gameplay of the CTA's initial subject (chosen, due to time constraints, for their representativeness of the iterative evolution the game narrative, i.e., all levels in Chapter 1 were sampled, then one level each from each subsequent chapter through Chapter 9, the final chapter of the game), nearly every one indicated the presence of one or more of the five design characteristics in question, oftentimes all five at once.

Figure 1. Implicit Rules and Rule Shifting

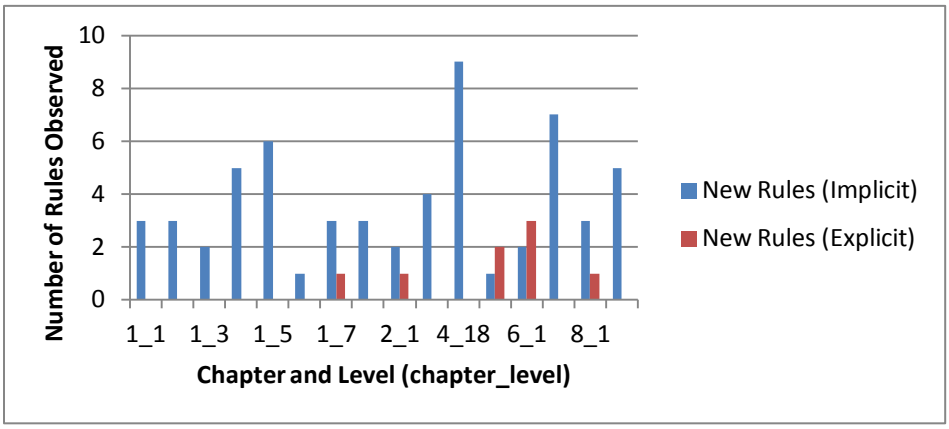


Figure 2. Environmental Changes

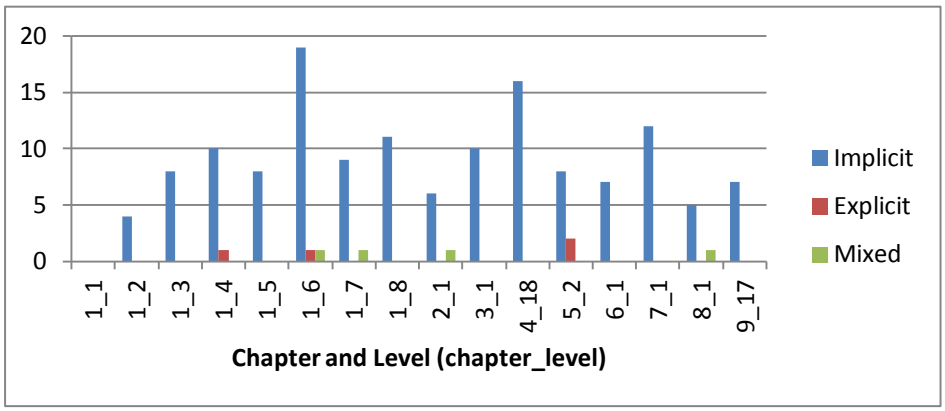
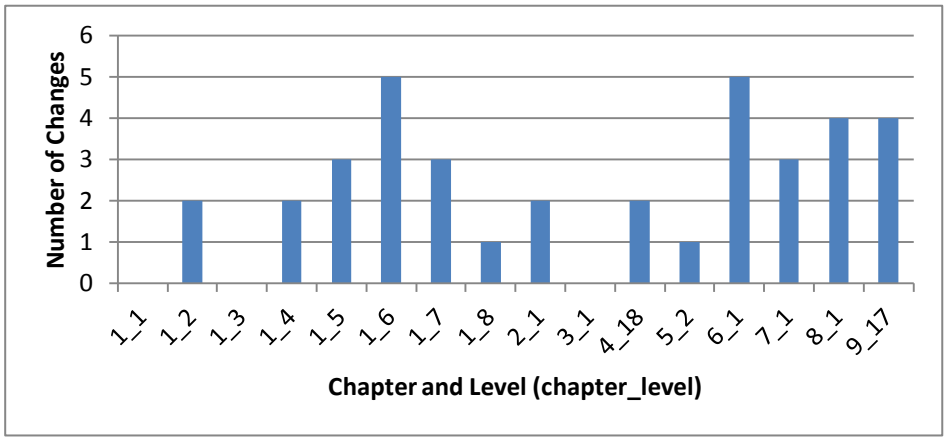


Figure 3. Reinforcement for Actions/Decisions



Additionally, Table 2 below shows the various instances of open-endedness reported by the player, and how many times each was noted within the sixteen levels sampled.

Table 2. Open-Endedness

Instance of Open-Endedness	Count in Sampled Levels
Time unconstrained	15
Choice of portal-shooting location	14
Multiple ways to accomplish task	16
General	1
of moving box	3
by utilizing portal sequencing and environmental features	2
of moving laser acceptor via reflection cube placement	2
of transporting self/objects	1
of retrieving defective turrets	1
of/while protecting self from avoiding bullets	1
via portal/paint placement	2
via variable distances/speeds that can be used successfully with paint	1
via multiple jumping-off points/heights that can provide necessary momentum for task	1
via varied choices of box-turret hybrids to interact with	1
Freedom of movement/access to different spaces	15
Multiple ways to gain access to spaces/rooms	2
Control placement of both orange and blue portals	8

FURTHER ANALYSIS VECTORS

Data produced in this type of analysis is initially qualitative and quite extensive. To date the researchers have performed an initial look at the puzzles, decisions, and knowledge within Portal 2. They have also mapped where and how specific design features occur within the puzzles (i.e., levels). An additional analysis procedure is the categorization of the puzzles and, specifically, the micro puzzles that exist within and across puzzles. It has been postulated that each new interaction and discovery of functionality that occurs is essentially a micro puzzle and that as that micro puzzle is learned and rules of interaction formed, it migrates into pre-requisite knowledge as a tool for solving other puzzles. By mapping these transformations, it may work to further explicate how rules are formed, what type of rules they become and how they change. This will also begin to allow insight into the cognitive load each puzzle presents. Previous research has looked at the measurement of working memory capacity before and after playing Portal 2 (Gallagher & Prestwich 2012; Gallagher & Prestwich 2013). Working memory capacity is important for cognitive adaptability (CA), and analyzing each puzzle and puzzle type for cognitive load characteristics could give insight into additional or modified design features promoting CA. One such addition may be that of timed play, which may produce or reduce cognitive loading of the puzzles but could function as a way to begin to automatize metacognitive awareness.

IMPLICATIONS

By performing a CTA on Portal 2, ADL researchers hope they will be able to pinpoint both what expert performance looks like cognitively and how the game's design features influence player cognition during gameplay. This is essential for understanding the cognitive impact of gameplay and game design, a key component of the growing effort to leverage games for educational purposes. The undertaking is also producing a novel approach to using cognitive task analysis to harness the potential of video games for improving learning and cognition, by providing framework and set of best practices for performing cognitive task analysis on games in the future. Leveraging commercial, off-the-shelf video games, which are already being produced independently by game developers for a built-in market, as learning tools and tools to enhance cognitive capabilities at the most fundamental level is a new field, and there is virtually no precedent for using cognitive task analysis to fully understand and map the cognitive

potential of a pre-existing video game's design. ADL's efforts in this regard are posed to open the gates for further refinement and research of approaches to cognitive exploration of video games, game design, and the cognition o gameplay in the future.

REFERENCES

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., & Rumble, M. (2011). Defining 21st century skills. Retrieved February 1, 2013, from http://atc21s.org/wp-content/uploads/2011/11/1-Defining-21st-Century-Skills.pdf.

Boyle, E., van Rosmalen, P., MacArthur, E., Connolly, T., Hainey, T., Johnston, B., Ger, P. M., Manjon, B. F., Karki, A., Pennanen, T., Manea, M., & Starr, K. (2012, October). *Cognitive Task Analysis (CTA) in the Continuing/Higher Education Methods Using Games (CHERMUG) Project.* Paper presented at the 6th Annual European Conference on Games-Based Learning, Cork, Ireland, UK.

Clark, R. E., Feldon, D. F., van Merrienboer, J. J. G., Yates, K. A., & Early, S. (2006). Cognitive task analysis. In Spector, J. M., Merrill, M. D., van Merrienboer, J. J. G., & Driscoll, M. P. (Eds.), *Handbook of research on educational communications and technology* (3rd ed.). Mahwah, NJ: Lawrence Erlbaum Associates.

Cooke, N. J. (1994). Varieties of knowledge elicitation techniques. *International Journal of Human-Computer Studies, 41,* 801-849.

Gallagher, Patrick S., and Shenan Prestwich. (2012). Supporting cognitive adaptability through game design. In Proceedings of the 6th European Conference on Games-Based Learning, 165–173. Cork, IE: 6th European Conference on Games Based Learning.

Gallagher, Patrick S., and Shenan H. Prestwich. (2013). Can game design be leveraged to enhance cognitive adaptability? Electronic Journal of e-Learning 11, no. 1 (Special Edition on Games Based Learning).

Grisogono, A. M. (2010, June). *Exploiting adaptation*. Paper presented at the Operational Adaptation Conference, Edinburgh, Scotland, UK.

Klein, G. A., Calderwood, R., & MacGregor, D. (1989). Critical decision method for eliciting knowledge. *IEEE Transactions on Systems, Man, and Cybernetics, 19,* 462-472.

Militello, L. G., & Hutton, R. J. B. (1998). Applied cognitive task analysis (ACTA): A practitioner's toolkit for understanding cognitive task demands. *Ergonomics, 41*(11), 1618-1641.

Partnership for 21st Century Skills. (2008). 21st Century Skills, Education and Competiveness: A Resource and Policy Guide. Retrieved May 2, 2012 from http://www.p21.org/storage/documents/21st_century_skills_education_and_competitiveness_guide.pdf.

Shute, V. J., & Kim, Y. J. (2012). Does playing *World of Goo* facilitate learning? In D. Y. Dai (Ed.), *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning* (243-267). New York: Routledge.

TRADOC (2010). *The United States Army learning concept for 2015*. Fort Eustis, VA: Author.

U.S. Department of Education. (2012). 21st Century Skills: A Global Imperative. Retrieved May 2, 2012 from http://www.ed.gov/blog/2012/03/21st-century-skills-a-global-imperative/.

U.S. Department of Labor. (1991). *What Work Requires of Schools: A SCANS Report for America 2000*, U.S. Department of Labor, June 1991, pp. xvii-xviii.

Wei, J., & Salvendy, G. (2004). The cognitive task analysis methods for job and task design: Review and reappraisal. *Behavior and Information Technology, 23*(4), 273-299.