*This paper is in press in the proceedings of the European Conference on Games Based Learning 2012, Cork, Ireland, 4-5 October (http://academic-conferences.org/ecgbl/ecgbl2012/ecgbl12-home.htm). Proceedings are forthcoming following the conference.*

# Supporting Cognitive Adaptability Through Game Design

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**Abstract:** 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 and the U.S. Department of Education. Video games are seen as learning environments supporting the acquisition of 21st century skills. Can games, then, be used as components of an effective learning environment that support the development of adaptability?

Initially this paper describes the metacompetency of adaptability. Next is how adaptability can be functionally and discretely measured by focusing on its most granular or micromomentary level which we describe as cognitive adaptability. Finally, the authors examine both the nature of cognitive adaptability, interventions that support its development, and how those interventions might be translated into game design features. Toward this end, the paper will also discuss how these features are exhibited in a popular commercially available video game and how it could be employed to test the hypothesis that a play frame of 12 consecutive hours, using a video game meeting the design criteria and example previously discussed, will increase cognitive adaptability in the players.

**Keywords:** Adaptability**,** Cognition**,** Cognitive Adaptability**,** Games**,** Serious Games

## 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 21sts 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, leverage generational differences, ubiquitous, easily accessible, and have broad appeal 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 computer-based games for training adaptability, it must be identified which design characteristics specifically contribute to an increase in cognitive adaptability. In defining these traits, the knowledge generated can be used to identify games currently available that might foster cognitive adaptability, as well as to design games in the future for the specific purpose of training adaptability. This requires gaining understanding of cognitive adaptability as a construct and how existing video games might be leveraged as a learning environment that could increase cognitive adaptability in the players.

## Cognitive Adaptability (CA)

An adaptive stance is an observed set of behaviors emanating from the quality of adaptability; however, adaptability itself can be described as a mode of thinking. Adaptability, as with other modes of thinking, is considered to be a competency that can be learned, measured, and assessed (Haynie, 2005).

Both adaptive stance and adaptability begin on a cognitive level. As a unit of analysis, the cognitive skills that contribute to adaptability provide a means to understand adaptability at the individual cognitive level not confounded by relational or dispositional variables. Cognitive adaptability exists mostly at the level of micro-momentary cognitive decision processes and is closely related to the concept of fluid intelligence, a

complex human ability that allows one to adapt to novel cognitive problems or situations and is critical to cognitive tasks and learning. Although long considered static and hereditary, there is compelling evidence that fluid intelligence is closely related to working memory and can be trained or improved (Jaeggi et al., 2008). These gains were shown to exhibit transference; however, it is not known if the effect is persistent over time (Sternberg, 2008). Good (2009) has discussed cognitive adaptability in the perspective of cognitive agility which consists predominantly of predominantly of cognitive openness, focused attention (the ability to attend to relevant stimuli and ignore distracting ones), and cognitive flexibility.

Metacognitive ability is a cognitive competency that has been tied as a contributing factor to adaptability by several past studies (Brown, Bransford, Cocking, Donovan, & Pelegrino, 2000; Haynie, 2005; Haynie & Shepherd, 2009). Brown et al. (2000) define adaptability as the ability to actively monitor one's levels of understanding, decide when it is inadequate, and adjust one's actions, thoughts, and decisions according to that level of adequacy, as well as to the current environment or situation. Closely associated with metacognition and considered a key component of cognitive adaptability is metacognitive awareness. Metacognitive awareness is the awareness of metacognition and of one's own metacognitive abilities (Moncarz, 2011) also defined as an aggregation of five dimensions of metacognition: goal orientation, metacognitive knowledge, metacognitive experience, metacognitive control, and monitoring (Haynie, 2005). These dimensions of metacognition are actuated through one's own metacognitive awareness with individual levels influenced through various experiences indicating positive correlation between metacognitive awareness levels and age.

Cognitive flexibility is the ability to cognitively control and shift mental sets. This ability requires the use of cognitive monitoring and cognitive control, which makes it often discussed as synonymous with metacognitive ability. Assessments of cognitive flexibility most often include assessments of working memory, divided attention, and shifting behavior. In addition to metacognitive awareness, cognitive flexibility is considered by many to be the key components of cognitive adaptability and crucial to adaptive expertise and problem solving (Canas, 2003; Haynie & Shepherd, 2009; Moncarz, 2011).

## Measuring CA

Assessment of executive function is difficult due to the range of and diversity of skills associated with it. No single test can assess all of its various components; therefore, a battery is required (Anderson, 2001). Cognitive testing using a battery allows components critical to cognitive adaptability (i.e., cognitive flexibility, focused attention, and fluid intelligence) to be assessed empirically (Cambridge Cognition, 2012) and have been validated recently through functional imaging (Anderson, 2001). Multiple battery administrations can be used as repeated measures, allowing the detection of changes over time. Typical battery components have been historically associated with the testing of executive control in subnormal populations due to the ceiling effect found in assessment tasks such as the Wisconsin Card Sorting Test (WCST) and the Stroop Color Test (Anderson, 2001). Currently, however, assessment tasks do exist as valid and reliable measures available to supernormal populations due to testing modes with high ceiling properties (Cambridge Cognition, 2011). Examples of these tasks and the modes which would allow these assessments are Attention Switching task (AST), Spatial Working Memory (SWM), Rapid Visual Information Processing (RVP), and the One-Touch Stocking of Cambridge (OTS) (Cambridge Cognition, 2011).

Metacognitive awareness as a cumulative construct can be assessed through a cumulative measure producing a snapshot of the level of an individual's metacognitive awareness as a function of life experiences over time. Through a series of 36 questions, a valid and reliable instrument called the Metacognitive Awareness Inventory has been developed, tested, and successfully deployed in multiple

organizational environments and academic studies (Haynie, 2005; Haynie & Shepherd, 2009; Moncarz, 2011).

## Fostering Cognitive Adaptability

There have been some research initiatives, such as the "80 Days" project (http://www.eightydays.eu/) from the European Union's Seventh Framework Programme for research and technological development, which have explored the relationship between games and learning, as well as narrative and design frameworks to make educational games more adaptive (Kickmeier-Rust & Albert, 2010; Kickmeier-Rust, Steiner, & Albert, 2011; Walsh, Rafter, Conlan, & Wade, 2011). Other research has focused on adaptive metacognitive support for non-game-based online training (Moore, Conlan, Dagger, & Wade, 2011). However, there is a dearth of literature directly describing design-based interventions in video games to foster or improve cognitive adaptability in the players. There are, however, directly related concepts and constructs in clinical and educational psychology from which principles of game design can be inferred.

Cognitive remediation therapy (CRT) is a neurocognitive psychotherapy technique aimed at improving three distinct executive functions: cognitive flexibility, working memory, and planning (Delahunty & Morice, 1993; Delahunty, Reeder, Wykes, Newton, & Morice, 1999). Though it was designed to benefit those with sub-normal abilities, its principles can be extracted and applied with increased complexity to cognitive flexibility training for psychologically healthy, unimpaired individuals and those with super-normal abilities and functioning as well.

CRT is divided into three modules, each focusing on a specific neurocognitive function (Wykes, Reeder, Landau, Everitt, Knapp, Patel, & Romeo, 2007), including metacognitive awareness and cognitive flexibility, two components of adaptability (also included is memory) and emphasizes cognitive "microskills." Many of the tests administered before therapy can increase cognitive microskills and include the Wisconsin Card Sort Test (WCST) (Wykes & Reeder, 2005) and the Stroop Color Word Test (also known as the Stroop Neuropsychological Screening Test) (Trenerry, Crosson, De Boe, & Leber, 1989), among others. The WCST (designed to measure "set-shifting" ability) (Berg, 1948) and the Stroop Test measuring directed attention are most relevant to fostering and measuring cognitive flexibility (De Young, n.d.; Stroop, 1935).

While practicing these tasks themselves can help strengthen cognitive adaptability microskills, there are several that have been shown to further improve cognitive flexibility: having the patient verbalize their responses to the task while performing it (Rossell & David, 1997; Stratta, Mancini, Mattei, Casacchia, & Rossi, 1994), increasing the amount verbal information contained in the task while still keeping the rules and relationships in the task purposefully non-explicit(Young, Zakzanis, Campbell, Freyslinger, & Meichenbaum, 2002), using scaffolding techniques (Young et al., 2002), and employing errorless learning, which uses positive reinforcement and shaping instead of correcting errors (Kern, Wallace, Hellman, Womack, & Green, 1996).

Halpern, Hansen, and Riefer's (1990) Feature Overlap Theory as well offers insight into how cognitive adaptability may be fostered. According to Halpern and colleagues, if training is too similar on a surface level to the actual event, when encountering a situation that requires them to use their skills in real life, they reach for superficial surface connections and fail to utilize their deep, causal understanding of the material. Accordingly, if the training teaches the trainee a deep, causal understanding of the material but is far enough removed, on a surface level (e.g., aesthetics, circumstances and details of a problem, etc), from an actual replication of reality, it forces trainees to exercise their ability to make deep connections and adapt their knowledge to new situations—and thus will result in a higher likelihood of increased

performance in any environment or situation, and a higher level of transfer as trainees successfully adapt to new or changing environments by applying their fundamental, causal knowledge in new ways.

## Game Design Features for Cognitive Adaptability

Successful methods of increasing metacognitive awareness and cognitive flexibility in other arenas can provide insight into design characteristics that could make a game an agent for increasing cognitive adaptability. Though some of the concepts drawn upon for insight into improving the cognitive processes that contribute to adaptability were designed for those with sub-normal cognitive capabilities, and could have a ceiling to their effectiveness for those with normal or above-average capabilities, their basic tenets can be extracted and applied in more complex and challenging ways to game design.

If using the MDA (mechanics, dynamics, aesthetics) model of game design proposed by Hunicke, LeBlanc, and Zubek (2002), where mechanics are the components of a game at the level of data representation and algorithms, dynamics are how the game components interact with the player and vice-versa, and aesthetics comprise the emotional response evoked by the mechanics and dynamics, the characteristics we posit below could be said to represent "features," or more accurately, "sub-features" within a set of features, a level of game design to come before mechanics in what could be deemed an "FDMA" model. These are the general design ideals, represented by a taxonomy of features and sub-features, which are then translated into the specific mechanics of a specific game, which then in turn are integrated into a game's specific runtime dynamics and evoke a particular aesthetic during gameplay. Their place within the FDMA framework is represented in Figure 1 below.

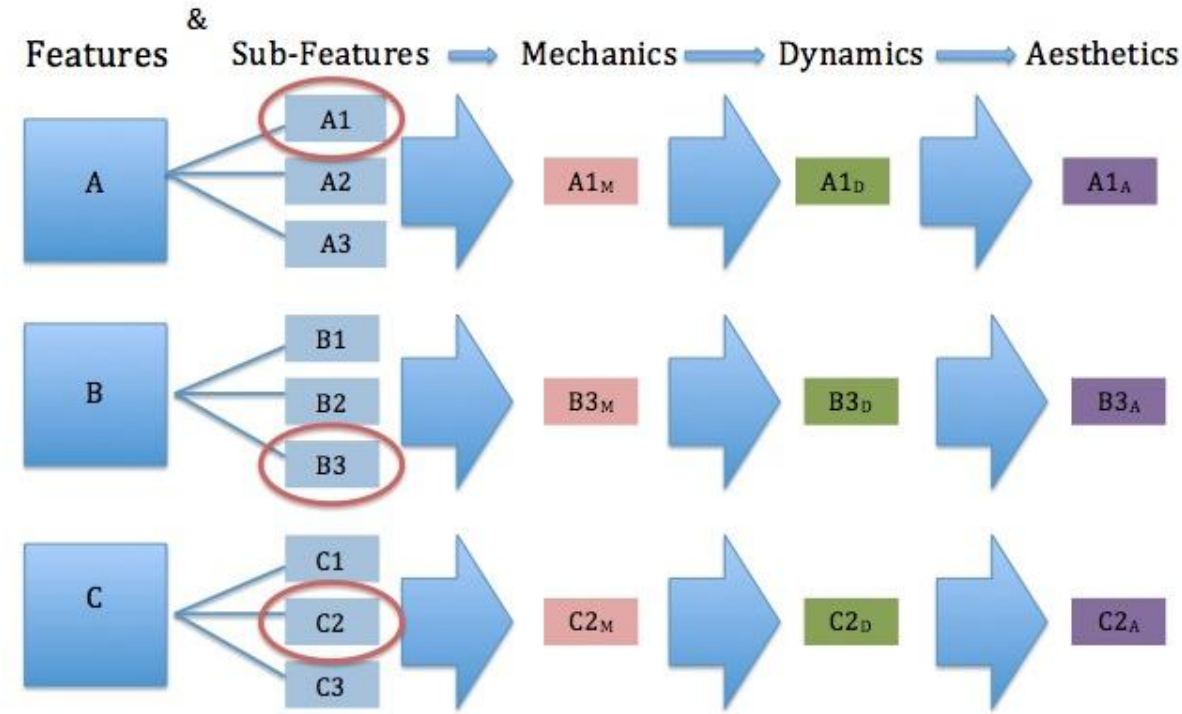


*Figure 1.* **FDMA Framework**

The features themselves are more design "categories," and the sub-features are the specific options of design ideals within the categories. For instance, in the diagram below, the features are "Rules," "Location," and "Conflict." The sub-features for each of these features would be implicit or explicit rules, realistic/high-fidelity or fantasy-based location, and violent or non-violent conflict.

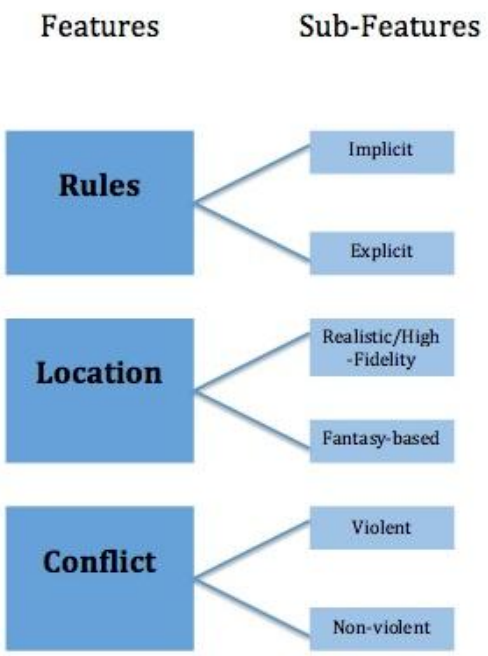


***Figure 2.*** **Example of Features and Sub-Features Extracted From Larger FMDA Framework**

However, not all sets of features and sub-features are this simple. There can, in fact, be an entire taxonomy of features, sub-features, and sub-sub-features that can be selected for at each level. Take the example of the "Rules" feature, below:

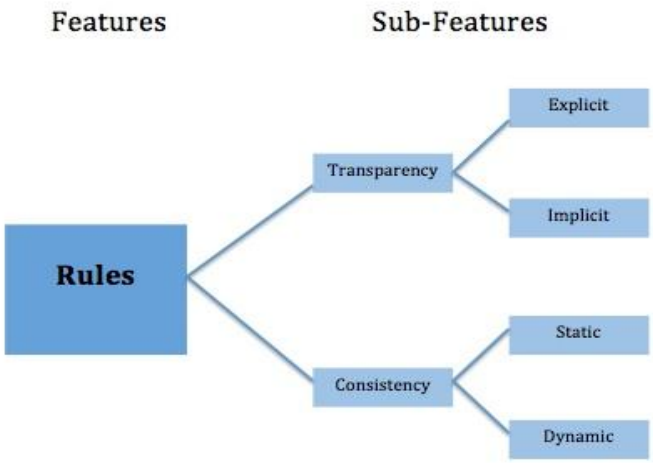


***Figure 3.*** **Example of "Rules" Feature with Taxonomy of Sub-Features**

Within the feature of "Rules," there are categories of "Transparency" and "Consistency," with various levels of consistency and transparency manifesting in sub-sub features.

It is with this theory of game design in mind that the following specific sub-features are posited to improve cognitive adaptability.

1. ***Unstated/Implicit Rules.*** The Wisconsin Card Sorting Test measures, and is used to improve, participants' cognitive flexibility by forcing them to determine unknown rules for sorting a deck of cards. Participants ideally reduce the amount of errors and amount of time it takes them to figure out these unstated rules, and their cognitive flexibility is measured as such. Therefore, a game or serious game which forces players to play by rules which are not stated explicitly should similarly enhance players' cognitive flexibility, and contribute to increased overall cognitive adaptability.
2. ***Unstated/Implicit Changing of Rules.*** Likewise, just as participants' cognitive flexibility is challenged, strengthened, and measured by changing the rules of card sorting without notice or explanation in the WCST, a game whose rules shift non-explicitly should show the same ability to produce gains in cognitive flexibility among players.
3. ***Dynamic, Shifting Environments***. Requiring trainees to reach for deep, causal understandings and apply their knowledge to situations that differ on the surface, in detail or circumstance, from their training situations, but retain the same underlying fundamentals, increases their adaptability by essentially forcing them to adapt. Therefore, games whose environments and surface/aesthetic details change throughout the gameplay should foster cognitive adaptability as well.
4. ***Open-Ended Game-Play.*** Cognitive adaptability) is comprised, in part, by cognitive focused attention, and cognitive flexibility (synonymous with metacognitive ability). Metacognitive ability was also shown to contribute to adaptability by Brown et al. (2000), Haynie (2005), and Haynie & Shepherd (2009). These components and correlates all point to the need for choices, the need to have more, as opposed to fewer, opportunities to choose a decision or action from a myriad of possible ones. Making choices requiring discerning relevant information from irrelevant information (focused attention), purposeful processing (mindfulness), a willingness to experiment and learn from doing (curiosity), and the creation of novel solutions from an expansive realm of possibilities (creativity), all of which require metacognitive processing. This all points to the need for game-play that is more open-ended than not, one that presents the player with opportunities to synergize solutions rather than choose from small, explicit list of possible actions, as well as think explicitly about and monitor their decision-making process along the way.
5. ***Implicit Reinforcement for Individual Actions/Choices to Achieve Final Goal.*** Implicit reinforcement for individual actions and choices a participant makes to achieve a final goal is a technique for fostering cognitive flexibility. Scaffolding techniques, which include modeling, verbal cues, and personal engagement of a student without explicitly instructing, as well as errorless learning, in which students are not corrected for their errors but positively reinforced for their successes, have both been shown to increase cognitive flexibility on the WCST (Kern et al., 1996; Young et al., 2002). The success of both these strategies at increasing cognitive flexibility suggests that players of a game should not be corrected for incorrect actions or choices they make along the way to achieving the final goal, but should see the results of their actions and choices explicitly in the final result. The results of their actions towards the final goal (and positive reinforcement should that goal be achieved) should be the only indication players have of whether or not their individual choices were correct. This also requires them to metacognitively assess their strategies and thought-processes for effectiveness.

## Experimental Design

To better understand how the above game design features will foster cognitive adaptability, a design should be constructed that compares game play time of a game possessing all or most of the features

described above to game play time spent on a generic set of games having static environments and explicit consistent rule sets. This design should include research questions addressing changes in cognitive adaptability before and after game play, extent levels of metacognitive awareness and prior game experience.

The choice of control is important to the outcome as it sets up the comparison, answering the question, “compared to what?” Previous studies have looked at the potential of cognitive capability increases after video game play but the comparisons used were to such things as looking up questions on the Internet or doing nothing (Jaeggi at al., 2008; Owen et al., 2010). To understand the utility of specific game design features, an appropriate control would be playing a video game that is identical in most respects to the experimental one but doesn’t possess the features under examination. In current research conducted for the U. S. Department of Defense, an experimental video game, Portal 2, provided shifting dynamic environmental settings and implicit shifting rule sets (experimental group) and was compared (in the control group) to four Microsoft video games having static environments and explicit, consistent rule sets (Solitaire, Minesweeper, Free Cell, and Mahjong). A mixed factorial design was constructed that compared cognitive adaptability characteristics of those playing Portal 2 (Valve Software), a game possessing all or most of the features described above, to a control group (between subjects design), and a within-subjects design comparing pre/post scores with levels of cognitive adaptability (CA) (Gallagher & Prestwich, in press).

Gallagher and Prestwich (in press) employed a within subjects design where cognitive abilities of participants were tested before and after 12 consecutive hours (six hours each day, broken into smaller sessions of gameplay divided by breaks) of monitored game play in 18-24 year old enlisted military personnel. Metacognitive awareness levels were also assessed prior to gameplay and changes in metacognitive awareness were assessed periodically during gameplay. The population consisted initially of 80 volunteers from the NCO (non-commissioned officer) enlisted population of technical trainees or as permanent parties, whose participation in the study counted towards continuing service hours. They were randomly assigned into experimental and control groups prior to the first day of gameplay.

Data were collected using four instruments. The primary instrument was the Cognitive Adaptability Battery customized specifically for this study using Cambridge Cognition’s CANTAB Eclipse software (Cambridge Cognition, 2012). Cognitive testing is notorious for having a ceiling effect as they are designed for testing sub-normal populations. However, these tests/tasks were able to switch to high functioning modes and were therefore sensitive for super-normal populations. Three other instruments were developed and deployed during three different phases of data collection. These consisted of the Metacognitive Awareness Inventory (MAI) (Haynie, 2005; Haynie & Shepherd, 2009), the Game History Questionnaire (GHQ) using questions from Moncarz’s (Moncarz, 2011) research in the relationship between playing games and metacognitive awareness (Appendix A) as well as Singer and Knerr’s (2010) Gaming Experience Measure, and the Active Metacognitive Questionnaire (AMQ) (Appendix A).

CANTAB data were collected three times during three weeks with Initial baseline data collected prior to pretesting to control for practice effects. The GHQ was administered to all participants after gameplay, so as not to influence their attitudes or performance during the intervention with self-perceptions of ability. Levels of metacognitive awareness were measured by the MAI, administered to all subjects prior to the intervention and immediately after pre-testing with the CANTAB battery. Metacognitive awareness was also tracked intermittently by students’ answers on the AMQ; administered at each break point to both the experimental and control groups providing a snapshot over time of changes to subjects’ metacognitive awareness during gameplay. Primary data collection occurred over four days, one week after baseline

testing: pre-testing on day one, gameplay interventions on days two and three four, and post-testing on day four. Gameplay of three subjects in the experimental group was captured in real time through FRAPS real time video capturing software.

## DISCUSSION

In looking over the field of commercial games, the researchers identified very few games that met the requirements for cognitive adaptability and none that met the complete set. As they were identified, it was apparent that some features were not usually compatible with the aesthetics typically designed into commercial game play and those possessing some of the features were of very different common categories. The game identified with most of the desired features was *Portal*™ by Valve Software. In various degrees it has features 1, 2, 3, and 5. However, the degree to which feature 4 incorporated is subtle and is under debate. This lack of clarity in defining features and categorization also makes it more difficult to choose and appropriate control games. Gallagher and Prestwich accomplished this using a set of ubiquitous Microsoft games found with the Windows 7™.

At the time this paper was written, data has been collected but not aggregated, collated, and analyzed. Gallagher and Prestwich (in press) are currently in the process of answering specific research questions using the data collected as described above These necessary steps will occur over the next 60 days and may be be presented orally during the presentation of this paper with specific results, findings, and in-depth discussions contained in further publications.

Gallagher and Prestwich (in press) noted, however, that even though the data have not yet been analyzed, there are anecdotal data that indicate positive outcomes. Volunteers were informally interviewed ad hoc after the final test and it was discovered that asking the metacognitive questions during Portal 2 gameplay may have sparked active MA. While not explicitly designed to do that the possibility was considered. This does indicate that MA spaced prompts could bring about more MA during types of activity requiring problem solving, shifting rule sets, and open-ended environments.

## CONCLUSION

In moving beyond current research outlined (Gallagher and Prestwich, in press), the question, “so what?” will also need to be answered. As a metacompetency, cognitive adaptability should exhibit transfer to other situations and contexts. Cognitive battery tasks are not the best at establishing ecological validity (the relationship between an individual’s performance on the battery and behavior in real-world settings).
Direct relevance to the external world would introduce many confounding conditions; however, it limits transference to these other contexts (Anderson, 2001). To check for persistence of change and true transfer, the experimental design should not end with the post-test data collection period. Provided causality in increasing CA is determined by game design, next steps in this area should include real-world tasks using a consistent population testing for transference to real-world conditions and changes in context. This is difficult on two fronts. These tasks are usually domain specific and may not exhibit true generalizability and therefore need to be carefully chosen. Also, maintaining a consistent sample population longitudinally has many risks. These were discovered over the relatively short time of two weeks using military subjects by Gallagher and Prestwich (in press).

However, in today’s worlds, developing adaptable soldiers and leaders is necessary in meeting today’s challenges in military environments. Similarly, in the civilian sector there is a need to develop adaptive scholars and educators capable of adapting to, or communicating, rapidly expanding new knowledge in virtually all academic disciplines; adaptive colleagues and collaborators capable of adapting to changing practices and procedures in the world of work; and adaptive citizens capable of adapting to a rapidly

changing society. To support this imperative, the researchers argue that commercial video games may be valuable components of an effective learning environment supporting the development of cognitive adaptability, and thus the greater construct of adaptability.

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