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SERO!: EVALUATING A CONCEPT MAPPING GAME FOR ITS POTENTIAL TO IMPROVE COGNITIVE CAPABILITIES

Brian Moon, Charles Johnston & Benjamin Tuxbury, Perigean Technologies LLC, USA
Robert Hoffman, Institute for Human and Machine Cognition, USA
Sean Guarino, Ryan Jarvis, David Young, Victoria Romero, Charles River Analytics, USA
Email: brian@perigeantechnologies.com; www.perigeantechnologies.com

Abstract. We are currently participating in a research project to investigate whether a training regimen including a Concept Mapping game, in combination with other cognitive game-based interventions, will increase cognitive capacities in high-performing adults. The goal of our effort is to put this training regimen through a series of rigorous tests of whether focused and deliberate practice can correlate to an improvement in adaptive reasoning and fluid intelligence. This paper describes the evidential base for our hypothesis that playing a Concept Map-based game will improve these cognitive capacities, the origins and implementation of the Concept Mapping game, and future directions.
Keywords: Sero!, Concept Mapping, Adaptive Reasoning, Problem Solving, Cognitive capabilities.

1 Introduction

We are currently participating in a research program to investigate whether a regimen of training interventions, including cognitive microgames and transcranial direct current stimulation (tDCS), may improve the adaptive reasoning and problem-solving capabilities of high-performing adults. The goal of our effort is to put this training regimen through a series of rigorous tests of whether focused and deliberate practice to determine if improvement in the games correlate with an improvement in adaptive reasoning skill.

Among the interventions proposed to improve adaptive reasoning and problem-solving skills is a Concept Mapping-based game – Sero!© – in which players associate randomly-selected concepts and interrelate them meaningfully. The game builds on the tradition of Concept Mapping (Novak and Gowan, 1984), and on the literatures on creativity and critical thinking in which creativity is generally defined as the discovery of new connections or relations among things that had not been combined previously.

This paper describes the evidential base for our hypothesis that the activity of Concept Mapping – i.e., playing Sero! – will improve adaptive reasoning skill. We also describe the origins and implementation of Sero! and future directions.

2 Evidential Base

As summarized by Hurley (2014), recent research suggests that adaptive reasoning skill and other cognitive functions may be improved through a variety of cognitive, neurological, and physiological interventions. Some of the research has been questioned on methodological and theoretical grounds, and very little of the research has focused on improvements in high-functioning adults. To our knowledge, no research has been conducted with regard to the notion that Concept Mapping as a cognitive activity may improve cognitive abilities, much less adaptive reasoning. However, previous research suggests that there are positive correlations between some aspects of Concept Mapping and adaptive reasoning abilities, and between the practice at game playing and in improvement in adaptive reasoning skill. We turn now to this research base.

2.1 Limited direct evidence of the benefits of Concept Mapping for adults

While there is vast evidence of the educational benefits of Concept Mapping (see CMC, 2004-2012), little is known about the potential *cognitive* benefits for adults. Moon, Hoffman, Novak & Cañas (2011) and Novak (2010) have described a range of applications of Concept Mapping undertaken by adults. The majority of the research has focused, on the utility of such applications for the intended uses—for example, as a method of structured analysis in the U.S. and Canadian intelligence communities (see Heuer and Pherson, 2011; Derbentseva et al., 2011). Some research has extended the typical focus on learning and assessment with Concept Maps into adult (primarily college- and post-graduate-aged) populations (c.f., Pottier, 2010). Moon, Ross & Phillips (2010) demonstrated potential for learning assessment with adults using Concept Maps. Still others have researched how different approaches to and implementations of Concept Mapping may affect the outcomes of the effort – i.e., the Concept Maps – using adult participants (c.f., Derbentseva et al, 2007). But to our knowledge, the question of whether the activity of Concept Mapping may influence the cognitive abilities of adults has not been addressed. Indeed, the empirical evidence for such effects on children must be inferred based on (hypothetically) related outcome measures, such as test-taking performances (Novak, 2010). We only have a vague idea that Concept Mapping as an activity may influence cognitive capacity. Whether the activity of Concept Mapping can actually *improve* cognitive capacities in adults has not been examined.

2.2 Tangential evidence of potential benefits

Concept Mapping at its most basic level involves the cognitive activity of association wherein two or more concepts are meaningfully related with each other: “Linking words or phrases specify the relationship between the two concepts” (Novak and Cañas, 2006). More than this, psycholinguistic research has shown definitively that people can find meaningful semantic relations among concepts that would ordinarily be thought of as unrelated. Hoffman and Honeck (1979) referred to this as the “semantic infinity hypothesis.” Although it can be difficult, people can interpret sentences that are syntactically and semantically anomalous, and can agree on the semantic similarity of the interpretations of anomalous sentences.

The correlation of associative thinking and creativity has long been known. Indeed, the Remote Associates Test has been widely used as a measure of creative capacity (Mednick, 1962). Benedek et al. (2012) concluded through experimental study that specific associative abilities, such as the ability to draw associations between words, qualify as valid elementary cognitive abilities underlying creativity. Some researchers have examined the connection between associative thinking and creativity by moving beyond simple word association paradigms to examine the basis of “semantic memory” (Hoffman and Honeck, 1976; Honeck, Reichmann and Hoffman, 1975). According to Gruszka and Edward Necka (2002), the “data suggest that creativity may stem from abundant *connections between concepts* that constitute the semantic network” (emphasis added). More recently, researchers have explored the relationship between neurological underpinnings and abilities to perform remote associations (Haarmann, 2012). Thus, we can consider research into associative thinking and creativity as part of the evidence base for the notion that the activity of Concept Mapping may introduce effects on the cognitive abilities of adults.

2.3 Evidence for the potential cognitive benefits of playing games

Recent research has demonstrated that batteries of short, focused, and engaging games can be useful for enhancing cognitive capacities, including working memory, cognitive flexibility, problem-solving, and inhibition. For example, Cogmed© has developed and researched game-based working memory (WM) training tasks that lead to significant improvements in children (Bergman et al., 2011), children with ADHD (Klingberg et al. 2005) and adult stroke patients (Westerberg et al., 2007). Jaeggi et al. (2008) showed that extensive training with WM tasks—in this case, the Dual N-Back Task—improves performance on independent WM tasks and on fluid intelligence tasks. Parallel work in industry has led to commercial microgame suites, including Brain Age©, Big Brain Academy©, Flash Focus©, and Lumosity© (Gwinn, 2008; Hardy and Scanlon, 2009), that provide a wide range of interventions for other cognitive capacities. While these games show enormous potential for improving cognitive performance, they have done so without significant empirical evidence and methodological control conditions that are desired to demonstrate actual effects – i.e., controlled behavioral and neurocognitive testing. It is therefore unclear if these tools are truly effective, and, even if effective, it is unclear whether any such effects may be due to game content or the presentation and potential engagement value of the game (Ackerman et al., 2010; Redick & Engle, 2006). Notably, the research has not established whether such games generalize to and across healthy adult populations, or whether the skills or concepts learned in the games actually show the desired “far transfer” to cognition in daily life or in professional work (Hoffman et al., 2013).

Concept Maps have been studied within game-based learning experiences. Coller and Scott (2009), for example, used Concept Maps as an evaluation instrument for a game based course. Their use was associated with students’ deeper understanding relative to a typical lecture-and-text based course. Kwon and Cifuentes (2009) used collectively constructed and individually constructed concept maps to explore their differing effects on learning through game play. But no previous research has explored Concept Mapping as a game.

Taken together, these research directions provide tentative support for the idea that purposefully engaging in game-based, associative thinking activities – e.g., Concept Mapping – may have positive benefits on adults’ abilities to be creative and solve problems. We are testing this notion through the use of Sero!.

3 Sero!

Sero! is a single-player, computer-based game based on some of the cognitive activities involved in Concept Mapping. The title "Sero" is derived from Latin for "I join together."

3.1 Origins

Sero! was conceived in 2012 during an introductory workshop on Applied Concept Mapping (Moon et al., 2011). The lead author, Mr. Moon, was introducing a group of patent attorneys, marketers and technical scientists from a major global food producer to Concept Maps and their potential use in brainstorming, project management, and knowledge elicitation. In order to stimulate an exercise in creating Concept Maps, Mr. Moon provided the group with a set of concepts that were well-known to the group and their work – e.g., "patents," "ingredients" – along with a few concepts that, ostensibly, were unrelated to the rest of the concepts or the group's work – e.g., "horse". During the exercise, it was apparent that the group was intensively engaged in the task of generating a *sensible* Concept Map from this mixed set of concepts. Interestingly, two participants asked whether a "right" answer was going to be provided at the end of the exercise – i.e., the participants assumed that the concepts could be associated with each other in such a way as to reveal an underlying puzzle or theme. Following the exercise, most of the participants reported enjoying the experience, though a few also noted some frustration at the lack of a "right" answer.

This experience – conducted with high functioning adults –suggested that Concept Mapping potentially held some appeal as a game, particularly when a fundamental idea from meaningful learning is turned on its head; namely, "the fundamental idea in Ausubel's cognitive psychology…that learning takes place by the assimilation of new concepts and propositions into existing concept propositional frameworks held by the learner" (Novak and Cañas, 2006). Sero! was designed to purposefully introduce random concepts in order to exercise a player's ability to impose a propositional framework on them, rather than to assimilate the concept into their existing framework(s).

3.2 Implementation

3.2.1 Rules

Sero! enables players to meaningfully relate a random set of concepts, under a set of game rules, and receive feedback on their resulting Concept Maps. For each game, the player is presented with a set of 6-12 randomly selected concepts (words) and a shape. The player is expected to relate all of the concepts into a meaningful diagram, using the traditional Concept-Relation-Concept propositional format. The concepts must be interrelated *in the context of a sensible theme*. Players can state the theme of their map at any time. The player may add a Wild Word (i.e., a new word of the player's choosing), if the option is available. A game provides for the use of 0, 1 or 2 Wild Words, but their use is optional in order to make the map cohere. The player is also expected to include the particular shape that is given *somewhere within the Concept Map*. Shapes are Fans, Chains, and Loops, as shown in Figure 1, and only require use of three concepts.

Figure 1: Sero! shapes.

Players receive a score for each map that is completed. Points are scored by: (1) relating and connecting concepts and (2) achieving the shape. Sero! also includes a mechanism for comparing linking phrases against a set of commonly used links – for example, "—is a—," and "—includes—." Only partial credit is earned for commonly used linking phrases.

3.2.2 Software

Sero! is currently implemented in HTML and Javascript. The main components of Sero! are the graphical user interface (GUI) and datastore. The components and their purposes are described in Table 1. Figures 2 and 3 show the current GUI components that are denoted in Table 1 with an *. Components in italics are available to and engaged by players.

Table 1: Components of Sero!

Component	Subcomponent	Purpose(s)
Graphical User Interface (GUI)	*Add Linking Phrase**	Create linking phrase
	Edit Mode	Edit and delete linking phrases
	Wild Word	Set number of Wild Words; Add a Wild Word
	Done Button	Activates Scoring Mechanism; Stores map and theme
	Theme Box	Enter theme for map
	*Shape Display**	Selects and displays shape; Displays shape achievement
	Springy Graph	Force directed graph layout algorithm that automatically positions words in relation to other words and linking phrases
Random Word Generator	Wordlists	Deliver sets of random words for each map
Scoring Mechanism	Score Displays	Calculate score for each map and display in GUI
	Common Linking Phrase Comparison	Calculate partial score for common linking phrases
Datastore		Store all propositions, maps, themes
Difficulty Manager		Set number of words and Wordlist based on players' cumulative score
Help		Instruct players about functions and rules
Nominate		Enable review of players' own maps, and self-nomination of maps for review by other players
Review		Enable review of other players' maps, and judging based on sensibility and creativity

Figure 2: Sero! Screenshot for Add Linking Phrase Subcomponent.

Figure 3: Sero! Screenshot for Shape Display – Chain Shape.

Of special interest are the use of the springy graph (see Table 1), and the nominate and review functions. The springy graph was implemented in order to reduce burden on the player of spatially organizing the map. The nominate and review functions were created to encourage players to create "good" Concept Maps, and to help players improve their skill at the game.

3.3 Similarities and Differences between Sero!, Concept Mapping, and Other Creativity Activities

Sero! shares many similarities with traditional Concept Mapping. Sero! is most similar to "select and fill-in" Concept Mapping (SAFI; Schau et al., 1997), with the obvious difference being that all of the concepts are to be used by the player. The SAFI has been broadly used as a learning assessment technique. Indeed, SAFI Concept Mapping has been described as the preferred approach for using Concept Mapping as an Interactive Computer Task in the United States' National Assessment of Educational Progress' Science Framework (WestEd and CCSO, 2011):

> *In a concept-mapping task, students should be given a set of six to eight concept terms and be asked to construct a map linking pairs of terms with directed arrows. Students should label each arrow with a word or phrase that explains the relationship between a pair of concept terms (p. 98).*

Sero! also uses shapes to challenge players. The shapes are reminiscent of common patterns observed in traditional Concept Maps. For example Kinchin and Hay (2000) identified spokes (radial structure in which all the concepts are related to a central or unifying concept), chain (a linear sequence in which each concept is only linked to those immediately above and below), and net (highly integrated and hierarchical network). Whereas Kinchin and Hay suggested these sorts of patterns may be indicative of learning, Sero! implements shapes as a constraint to the play.

In our observations, playing Sero! involves both deductive and inductive thinking processes—where deductive is thinking from theory/theme to facts/words, and inductive is thinking from facts/words to theory/theme. That is, players can sometimes see a set of concepts and quickly grasp a unifying theme; for other games, players associate the concepts piecemeal, building toward a unifying theme. Flores (2009) observed in the context of mathematics education that Concept Mapping enables both processes. Pierre Pottier (2010) used Concept Maps in conjunction with a think-aloud protocol to assess medical problem-solving skills as a means of diagnosing how their students think when they are confronted with clinical problems—i.e., whether they used inductive or deductive reasoning. Concept Mapping seemingly supports both types of thinking, and playing Sero! enables players to experience and exercise both.

Sero! is also different from traditional Concept Mapping. The goals of playing Sero! include playing and achieving a high score. While enjoyment has been studied as a mediating factor in the use Concept Mapping in learning contexts (Schaal, 2010), and the advantages of play for learning have long been known (Zigler, 1972), learning and playing are not the same goals, particularly when play involves achieving and accumulating a score or other achievement. In an interesting exploration of the interplay of Concept Maps, games and fun, Charsky and Ressler (2011) examined students' motivation to learn history concepts while playing a commercial, off-the-shelf computer game. They found that using a conceptual scaffold – i.e., Concept Maps – to support learning may actually decrease students' motivation to learn classroom material through game play. They suggested that the Concept Maps make game play less autonomous, creative and active. In the words of one of the student participants: "Games are made for one purpose: fun," whereas the Concept Maps were seen as a learning activity that took away from fun. Sero! is intended to be fun. In a series of demonstration events with children and (young) adults, we have observed that many players thoroughly enjoy the experience, as evidenced by comments such as, "When can I have this?," "I don't want to stop playing!," and "I could get addicted to this!" We speculate that Sero! can drive better cognitive improvements because players will be more driven to play what is ultimately an engaging game experience. Indeed, positive affect inducing experiences have been shown to facilitate problem solving and creativity skills, including associative thinking (Isen et al., 1987). Whether Sero! can induce similar effects through practicing such skills while having fun is the focus of our research.

Currently, the scoring of performance in Sero! is a function of achievements – i.e., linking words and making shapes. Below we discuss future directions with scoring. But it is important to note that Sero!'s approaches for assessing achievement are quite different from most of the uses of Concept Mapping to assess learning achievement, and different still from methods to evaluate the "goodness" of a Concept Map. Scores and other elements of achievement in Sero! (e.g., within-game indications, such as animations) are tools for satisfying psychological needs that can be fulfilled by the playing of games, for example competing for rewards and feeling competent and creative (Tekofsky, 2014). Chatfield (2010) summarized seven features used by popular video games to create a reward structure that uses a person's natural inclination to associate certain activities with pleasurable neurotransmitter release, increasing engagement and providing the motivation to continue playing for long periods of time. These features include experience bars to measure progress, multiple long-term and short-term goals, rewards for effort (and uncertainty in those rewards), clear feedback, and narratives linking different aspects of a game. Sero! incorporates features like these in an effort to enhance the play experience. Thus, being good at playing Sero! does not equate to being knowledgeable about any particular topic, or even being good at traditional Concept Mapping.

Sero! also disregards the traditional "semi-hierarchical" morphology that defines "good" Concept Maps (Moon et al., 2011b). Our initial reason for implementing the springy graph was to relieve players of the task burden of moving concepts, and thus maintaining players' primary focus on creating associations. Observations of players revealed an unexpected benefit: the animation of the springy graph enhances the enjoyability of the game, as indicated by comments such as, "I really like how it moves around." While spatial orientation is certainly a key element in traditional Concept Maps, watching the shape of one's map emerge through animation is fun for players of Sero!.

Sero! can also be compared to other creativity measurement activities. To our knowledge the activity of word associations has not been studied for its potential to enhance adaptive reasoning skill. The specifications of associations in Sero! is much closer to traditional Concept Mapping than typical word association tasks and games (c.f., Nelson et al., 1998) in which a single word is presented and a second word that is thought to be associated with the first is elicited from a player. Games that build on this approach include Word to Word© in which lists of word are provided for a player to match, and Chain of Thought© in which sets of words are provided for a player to associate serially. Sero! requires players to describe specific relations to form an integrated set of propositions, in the tradition of Concept Mapping.

4 Sero! Research

Our team is participating in a program to develop and test interventions proposed to improve adaptive reasoning capabilities. Sero! is part of a broader suite of interventions that includes other "brain training" microgames, mindfulness practice, and tDCS. These interventions will be tested in a series of experiments to determine whether and how they may affect adaptive reasoning capabilities. Of interest for Sero! is the integration of Sero! with other microgames.

4.1 Brief review of development process

We have built and are refining a set of four microgames, including Sero!. The other three games are grounded in existing instruments for measuring putative components of adaptive reasoning – e.g., working memory, cognitive flexibility, and inhibition. These instruments are commonly used in neurocognitive studies because they link task performance to presumed neurological mechanisms. We have constructed games that are designed to improve these capabilities through a challenging regime of increased difficulty and cognitive challenge. Sero! provides a fourth game that we hypothesize is more directly linked to creativity, which we also believe will enhance adaptive reasoning. We are empirically testing each of these games separately, and the combination of the games as a full-scale intervention, in our ongoing research.

4.2 Brief review of experimental design

Our empirical studies will test whether the various features of our microgames provide for interventions that improve adaptive reasoning for high-performing adults. We are conducting research to understand causal relations between training, task performance, and neural activity.

In early phases of the program, participants will play the games for a set period of time (e.g., 40 minutes per day, five days per week, over the course of four weeks), either playing one of the four games alone, or splitting time equally between the four games. We plan to identify the conditions under which different microgames might be used for different individuals to tailor the games. We will collect pre-, during- and post-intervention measures of cognitive performance and neurophysiological impacts. In later phases of the program, the selection of the games will be tailored to individual participants on a weekly basis. Additionally, in our later studies, subjects will be scheduled to visit a lab once per week for an in-person training session in which the cognitive microgame intervention will be paired with tDCS treatments targeting the associated brain regions.

4.3 Challenges to demonstrating effects

There are many challenges to demonstrating the potential effects of practice at Concept Mapping on an individual's adaptive reasoning capabilities. First and foremost is the challenge of creating a game experience based on Concept Mapping, especially a software-based game. There are clear advantages to playing Sero! as a software game – e.g., ease of serving turns to players, calculating scores, tracking player progress across games. However, implementation has been challenged by the tradeoff between ensuring high quality gameplay and stifling creativity. For example, the semantics for creating linking phrases are not restricted, as is the case with traditional Concept Mapping. Players are free to create the links that make sense to them and in the context of their themes. While computer capabilities such as spell-checkers and natural language processing (NLP) tools can be useful for mitigating the use of junk linking phrases (i.e., strings of text that are not words), imposing these technologies can disrupt fun (as in fixing spelling errors) and the discourage creativity (as in NLP processes not appreciating the nuance of meanings and language).

Another challenges lies in the difficulty of determining causality in our experimental tests. We face two challenges here. First is the challenge of isolating the effects on performance of playing Sero!, given that participants will engage in other interventions. While this challenge can be partially addressed through experimental design, isolating effects without the possibility of confounds is a challenge for any program of cognition research. Indeed, one particularly challenging confound within our experimental design concerns the potential mediating effect of motivation (i.e., "fun"). Our participants will be engaged in an experiment, and thus will be motivated by factors in addition to fun. Morever, it is likely that while some may find playing Sero! to be fun, not everyone will. Teasing apart the "fun factor" and its effects on performance will be difficult. Another challenge will be correlating the activity of Concept Mapping with underlying neurocognitive functions. Neurocognitive correlates for complex problem-solving tasks tend to be more spread out across a range of regions (Anderson et al., 2005, Danker & Anderson, 2007). It is likely that our results will serve to point to new hypotheses about what happens in the brain when adults engage in Concept Mapping.

5 Future Directions with Sero!

We have described Sero! and its role in our experimental program, which will be ongoing throughout 2014. We expect the results of the experimental efforts by 2015 to demonstrate whether the activity of Concept Mapping holds the potential to improve adaptive reasoning capabilities in adults.

We also expect to continue to develop Sero! in several directions. The development of app versions of Sero! is underway, allowing for tablet and smartphone play. Such versions will also allow for the introduction of social play, beyond the nominate and review functions that are currently implemented. Given the psychological rewards that we believe Sero! can stimulate, enabling social play should serve to enhance the play experience by magnifying the value of the rewards through social interaction. Indeed, we have observed many instances of players wanting to share their Sero! maps with friends. We also envision additional user controls of the game elements (e.g., word lists) and experience (e.g., increasing difficulty level, time limits), introducing new shapes and interactions, and repurposing Sero!'s architecture for other uses.

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