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Spatial Intelligence as Related to Success on Regular and Constrained Electronic Puzzle Formats

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Keywords: *spatial intelligence, engineering games, scientific puzzle games, STEM games.*

GJCST-A Classification: *I.2.1, I.2*

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Keywords: spatial intelligence, engineering games, scientific puzzle games, STEM games.

I. Introduction

The theory of multiple intelligences (Gardner, 1983) that included: linguistic, logical, visual/spatial, bodily/kinesthetic, musical, interpersonal, and intrapersonal intelligences has undergone scrutiny (Almeida et al., 2010; Visser, Ashton, & Vernon, 2006), resulting in his further explanation of the theory (Gardner, 1993b). In the sequel a decade later, Gardner reiterates that each human being has intelligences that operate discreetly in the brain. In addition to the previous books, in *Creating Minds* (Gardner, 1993a), he examined the lives of seven individuals whose heightened capacity in one of the intelligences elevated them to success and further supported the theory. However, Gardner reiterates that the theory was never intended for the development of pedagogy to elevate intelligences. He suggests however that should educators use the theory pedagogically that teachers should individualize and pluralize (p. xvi). The former means to assist the development of intelligences in each child and the latter to present topics employing multiple means that incorporate intelligences identified in the theory.

For a decade following the unveiling of the theory, educational settings applied the theory in various ways to align and create curricula that include the intelligences (Armstrong, 1994; Hoerr, 1994; Krechevsky, Hoerr, & Gardner, 1995; Tamilselvi & Geetha, 2015). The studies showed ways in which the theory was applied, however limited evidence from these studies suggest that measures of intelligences were engaged and progress toward increasing intelligences were observed. Since the advent of standardized testing, ushered in by No Child Left Behind legislation (Klein, 2015), the primary intelligences that are tested and taught are linguistics and mathematics.

STEM education, with focus on science, technology, engineering, and mathematics, supports testing in mathematics, and in some situations science, particularly at the middle and high school levels, was initiated by the National Science Foundation in 2001 (White, 2014). Since that time, mathematics and science have remained the most emphasized of the four disciplines. According to White most school personnel are familiar with math and science, and/or have no mandated/tested curriculum for engineering. In 2009, the Educate to Innovate Initiative, signed by President Obama ("Education: Knowledge and skills for the jobs of the future," 2016), set out to challenge science and mathematics achievement, promoting STEM, rather than all four disciplines of STEM.

Though the initiative showed progress toward promoting improved math and science learning, support for the spatial intelligence necessary for engineering and technology remained elusive. The location of objects, relationships to one another, and the paths taken when in motion, all necessary for the development of engineers (Newcombe, 2010), remains unsupported in initiatives. However, spatial intelligence, if supported and promoted could serve as meaningful building blocks in developing engineers. As pointed out by Gardner, a learner endowed with a particular intelligence will seek the highest levels of learning in that area. For spatially intelligent learners, this would require seeking support for that learning outside of normal schooling and testing, possibly in virtual gaming environments.

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As of this writing, few studies investigate the relationship between spatial intelligence and engineering education. A recent study (Ha & Fang, 2016) laments the lack of scholarly attention given to this aspect of skill acquisition in engineering mechanics. A foundational understanding of mechanics, they argue, lies not only in understanding the physics and mathematics involved, but also the ability to make abstract connections between concepts and to understand spatial relationships. Yet, this connection remains largely unexplored. We were only able to locate one study on spatial learning, which focused on using a web-based drawing tool for engineering graphics, with learners who had no prior technical drawing experience (Pedrosa, Barbero & Miguel, 2013). While their study did demonstrate a small marginal gain in understanding among spatial learners, the study focused on drawing schematics rather than on problem solving through spatial reasoning.

Virtual gaming that involves problem solving has potential to tap into multiple intelligences. A recent study demonstrated that problem solving in mathematics classrooms engages more types of learning and can lead to increased comprehension (Rahbarnia, Hamedian & Rhadmehr, 2014). Beyond mathematical instruction, virtual gaming also has the potential to elucidate the ties between intelligence and problem solving skill. Bühner and colleagues (2008), echoing previous work (Ackerman & Lohman, 206; Ackerman, Neier & Boyle, 2005), find that spatial intelligence related to problem solving is different from working memory, defined as the memorization and application of rules. Game simulations can engage both intelligence and memory as players find ways to apply rules in order to solve more complex types of problems.

The mapping game, UNTANGLED described below, extends this research. In it, players operate within a spatial environment and must find ways to create a compact arrangement of circles within blocks. There are a number of rules, or types of moves, they are allowed to make. Then, a constraint is added in which they must adhere to a more general rule. We predict that spatial learners, under the constraint, will find ways to solve the problem by using more moves, and multiple moves, in order to obtain higher scores. Successful players are not merely applying the same rules, they are finding novel ways to combine moves to reach a spatially-oriented objective.

II. Problem Statement

Spatial learners are rarely challenged to increase spatial intelligence in normal school settings. There are currently few means by which to determine spatial intelligence among learners within the educational setting.

III. Purpose of the Study

The purpose of the study was to examine the success rate of spatially capable learners in regular and constrained versions of the same game puzzles.

IV. Question

Are there significant differences, at the p=.05 level, between selected moves made, scores obtained, and number of moves, made by spatial learners, in regular and constrained forms of electrical engineering puzzles.

V. Background

In this study, we have used an interactive online scientific puzzle game, UNTANGLED. The game is available at *https://untangled.unt.edu.* UNTANGLED was created to uncover human mapping strategies and discover better, efficient mapping algorithms which reflect the human characteristics such as creativity, pattern recognition, learning with experience. The game has been online continuously since 2012 and it has attracted large number of players who have contributed towards database of solutions. It has been recognized in several press releases. The game is created to be broadly accessible to everyone. Players do not need to have any special engineering background to play this game. The in-depth tutorials in the game help them learn about the game interface, and goals and objectives of the game. Several incentives such as medals, badges are given to players in order to motivate them. There is a leader board in the game where players can check their standings as compared to the rest of the players. More details about the game can be found in (Mehta 2013).

VI. Experimental Set-Up

In this section, we describe the experimental set-up that is used to conduct this case study. The experimental protocol for all studies was determined to qualify for an exemption from the Institutional Review Board (IRB) of our university. IRB protocols were followed in all cases. We considered six games, three of them are regular games and the other three are constrained games in which players have to follow some additional constraints. There are seven levels/puzzles in each game. The puzzles considered in this study are selected from the signal and image processing application domain. These include sobel (P1), laplace (P2), gsm (P3), adpcm decoder (P4), adpcm encoder (P5), idct row (P6), and idct col (P7). The number of blocks and connections in these puzzles are shown in Table 1.

Table 1: Basic information related to puzzles/levels considered in this study

Puzzles	P1	P2	P3	P4	P5	P6	P7
Blocks	24	29	29	29	36	52	61
Connections	29	29	34	36	53	63	72

In total, we have 42 cases (six games and 7 levels per game) considered in this study. An example of a puzzle in a regular game and its constrained counterpart is shown in Figure 1.

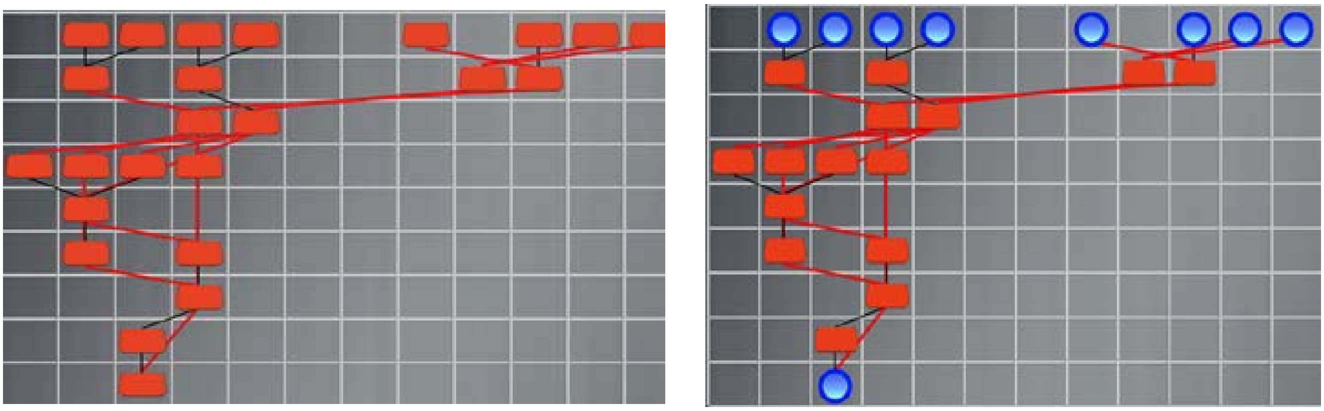

Figure 1: An example puzzle from a regular game (Left) and its constrained version (Right)

In the constrained games, there are two kinds of blocks – red rectangles and blue circles. Players have to follow the constraint of keeping blue circles around the periphery of the puzzle in addition to follow the connectivity and reach ability rules. Regular games only have red rectangles and they can be placed anywhere on the grid as long as connectivity and reach ability rules are met. The connectivity rules used in these games are 8way, 4way1hop, and 4way2hops. In an 8way, a block can connect to any of the eight neighboring blocks – top, bottom, left, right, and diagonally. In a 4way1hop, a block can connect of any of its four immediate neighbors (top, bottom, left, and right) and it can also make one hop in each direction (horizontal and vertical). In a 4way2hops, a block can connect to four of its immediate neighbors and it can also make two hops in horizontal and vertical directions. The goal of the players is to come up with compact arrangements of the blocks on a grid. We use a scoring function that guides players during the game play. We also show a violation count that helps players keep track of their progress and moving forward towards feasible or valid solutions. We record all the moves players make during the game play. Moves of all the levels of the games were analyzed thoroughly and results are presented in the next section.

VII. Results

Two statistical tests are used to measure the strength of game type and game level under the unconstrained and constrained conditions. The results of the ANCOVA are displayed in Table 2. The dependent variable is "total moves" and the category variable is "game session." The model, therefore, tells us the between subject effects of "game level" and "game type" on total moves under the regular and constrained versions of the game. The effect of the covariate, game session, is highly significant. The subsequent ANOVA of the residual further tells us that the game type and game level variables also have a strongly significant effect on total moves even after the effect of the covariate has been calculated. This provides support for the hypothesis that each variable exerts a strong effect on the number of total moves employed by the player under differing conditions of the game. However, since the ANCOVA is an omnibus statistical test, it cannot really tell us much about the direction of the relationship, but only the strength of the covariation.

Table 2: ANCOVA Results of Total Moves, with Game Session Covariate

Source	Mean Square	df	F
Game Session	28925.622	1	10.853***
Game Type	449926.502	2	186.809***
Game Level	283823.301	6	106.489***
Intercept	587275.654	1	220.432***
Error	2665.293	1586	

*** *p < .001*
N = 1608; R Squared = .478 (Adjusted R Squared = .471)

Table 3 is a multi-level fixed effects model, testing the effect of the constraint as a grouping variable on total moves. A mixed effects model allows us to examine independent between-subject effects of each variable and how they vary or co-vary under the categorical variable. Game type and game level are nested variables in this analysis. The model performs similarly to the ANCOVA; both game type and game level are strongly associated with the number of total moves. The intercept is also notable, as it shows that the unconstrained version results in fewer total moves than is seen in the constrained version of the game. Thus under the constraint, game players are likely to employ more moves in order to reach the objective.

Table 3: Multi-Level Mixed Effects Model of Total Moves, Grouped by Game Session Variable

Variable	Coefficient	Standard Error
Game Type	10.088	2.067***
Game Level	18.759	0.898***
Intercept	-26.233	6.198***
Residual	62.429	1.102
Wald $\chi 2$ = 465.46		

*** *p < .001 N = 1608*

LR test vs. linear model: ChiBar2(01) = 2.79 Prob >= ChiBar2 = 0.0474

It is useful to look at the relationship graphically. The number of total moves under the unconstrained and constrained conditions is displayed in the bar graph in Figure 2. Under the unconstrained version, the mean number of total moves is 49.83 (SD=55.53) and increases to 58.31 (SD=83.49) under the constrained condition. Not only do players employ more moves under the constraint, but there is a much wider variance in the number of moves between constraint conditions.

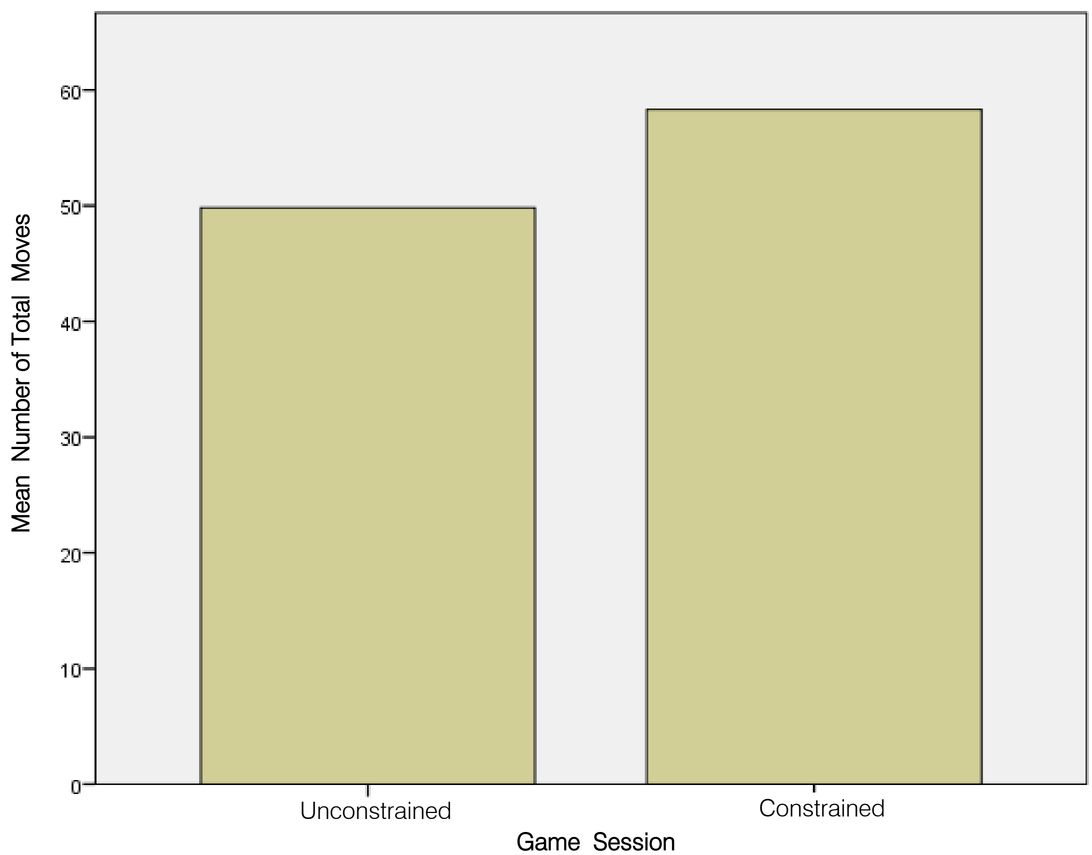

Figure 2: Mean Number of Total Moves under the Constrained and Unconstrained Conditions

Also illustrative is the types of moves employed under the constraint. As shown in Figure 3, not only does the number of total moves increase, but specific types of moves increased under the constrained condition. As described above, the number of single moves increased substantially (F=4.979; p<.026). However, multi moves increased slightly between the conditions (F=0.501) as did swap moves (F=0.057), indicating that the number of these types of moves did not vary substantially between the two game regimes. The number of add-pass moves, on the other hand, doubles under the presence of constraint (F=15.725; p<.001). These two types of moves, the single and add-pass, were frequently employed by game players as a means of overcoming the constraint.

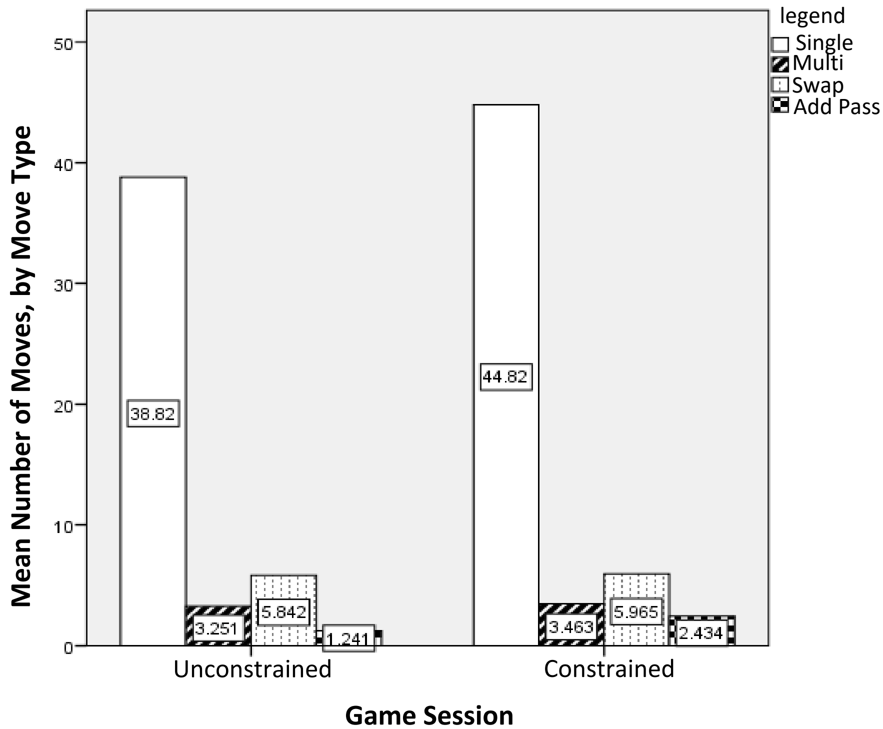

Figure 3: Comparison of Mean Number of Move Types under the Constrained and Unconstrained Conditions

VIII. Discussion

Spatially intelligent responders to the regular and constrained puzzle format of the same game showed significant differences at the p=.05 level, indicating a level of spatial intelligence that is unprecedented, due to the low percentage of players who responded. These respondents showed signs of spatial intelligence necessary to solve electrical engineering problems. In addition, the findings demonstrate that when spatially intelligent participants have the chance to challenge themselves, they seek the opportunity, using additional moves and more complex moves to solve the electrical engineering puzzles. The findings suggest a valuable use for electronic puzzles/games to determine which students are spatially intelligent, and potentially suited to engineering. When STEM was defined, the engineering definition stated that: Engineering is the art or science of making practical application of the knowledge of pure sciences, as physics or chemistry, as in the construction of engines, bridges, buildings, mines, ships, and chemical plants (White, 2014) p. 4. Findings from a study of architecture students (D'Souza, 2007) noted that students who excelled in spatial intelligence showed higher levels of skills and competencies needed for success as architects. The Design Intelligence Assessment Scale was used to determine both pedagogy and admissions for students into engineering programs that lead to architectural design. This tool extends the understanding of spatially intelligent learners, providing a means by which to ascertain later success.

The highly significant covariation in the results section shows that players are indeed responding to both the constraint and to the game level by learning new strategies. The fact that these moves are generally more complex indicates that spatial learners are employing a dynamic process of reasoning as the conditions of the game change. Since the game is designed to measure the ability to use intuition and pattern recognition to solve complex spatial puzzles directly related to engineering problems, this study builds upon the previous research on engineering competence. Understanding this type of competency can be useful in not only predicting success in engineering education, but also as a means of studying the ways that spatial reasoning is employed by engineers in solving design problems.

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IX. Conclusion

In addition to tools for assessing spatial intelligence, game designers can support spatial intelligence diagnosis and learning through game design. As in the case of UNTANGLED, the participants who chose to engage in extended spatial challenges demonstrated both skill and tenacity as they worked through both regular and constrained games. STEM educators could use spatial puzzles to identify potential STEM students, with a propensity for engineering. In addition, teachers could use the data from spatially directed puzzles to challenge students to heighten levels of spatial intelligence by using puzzles in non-STEM environments.

Among the intelligences studied and supported by years of research by Howard Gardner and those who followed, spatial intelligence remains on the fringe of consideration. The advent of STEM in the past twenty years has primarily supported mathematics and science learning, rather than engineering and technology. The results of this study demonstrate that supporting spatial intelligence can lead to valuable solutions to engineering problems. It would seem prudent for STEM educators to review Gardner's theory of multiple intelligences and consider the importance of all, including spatial intelligence, as well as mathematics and scientific thought.

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