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Game Over for Tetris as a Platform for Cognitive Skill Training

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Abstract

Despite popular enthusiasm for using computer games as a way to train educationally relevant cognitive skills, a review of the research reveals a frequent lack of transferable learning outcomes resulting from computer game play (Mayer, 2014). One explanation could be that computer game environments are fast and forward-moving, whereas learning that leads to transfer is reflective, effortful, and requires integrating new information with prior knowledge. What can be added to computer games to facilitate learning that transfers outside of the game context? This study investigated how to train transferable spatial skills with *Tetris*. In Study 1 (value added study), participants who played *Tetris* along with explicit instruction in Tetris cognitive strategies across 4 sessions did not show greater gains in 6 cognitive skills, including spatial and perceptual skills, than participants who only played *Tetris* across 4 sessions. In Study 2 (cognitive consequences study), participants who played *Tetris* in Study 1 did not show greater gains in 6 cognitive skills than participants who did not play *Tetris*. This research demonstrates the failure of *Tetris* to train cognitive skills even with evidence-based training enhancements, and highlights the idea that fast-paced computer game playing can foster highly specific skills that do not transfer.

Keywords: computer games, spatial skills, transfer

1. Introduction

1.1 Rationale and Objective

"You can play computer games after you finish your homework." Parents have been saying things like this to their children for decades, but computer game visionaries foresee a future in which playing computer games *is* the homework (Gee, 2003; Prensky, 2006; McGonical, 2011). For example, Prensky (2006, p. 4) asserts: "Kids learn more positive, useful things for their future from their computer games than they learn in school." Computer game proponents and visionaries claim that playing computer games can improve your mind. However, such claims are rarely backed up with compelling research evidence, particularly when operationalized as the claim that playing computer games can improve cognitive skills such as spatial skills (Honey & Hilton, 2011; Mayer, 2014; O'Neil & Perez, 2008; Tobias & Fletcher, 2011).

The goal of the present study is to test the claim that playing the classic spatial puzzle game *Tetris*, which has been called "the greatest computer game of all time" (McGonical, 2011, p. 23), can improve cognitive skills. We accomplish this goal in two ways-- by addressing what Mayer (2014) calls the *value added question* and the *cognitive consequences question*. In value added research, we compare the learning outcome of a group that is assigned to play a base version of a game versus a group that plays the same game with one feature added. In the present study, we compare a group that plays *Tetris* for 4 sessions (Tetris group) with a group that plays *Tetris* for 4 sessions along with directed training on effective spatial strategies for *Tetris* in each session (enhanced Tetris group). If the enhanced Tetris groups shows greater gains in cognitive skills than the Tetris group, we can conclude that adding strategy instruction increased the effectiveness of playing *Tetris*. The design of Study 1 allows for a direct test of the value added research question by determining whether adding a feature to playing Tetris results in improvements in transfer test performance.

In cognitive consequences research, we compare the learning outcome of a group that is assigned to play a game with a group that engages in an alternative activity. In the present study, we compare a group that plays *Tetris* (Tetris group or enhanced Tetris group) with a group that does not play *Tetris* (inactive control group). If groups that play *Tetris* show greater gains on cognitive skill tests than groups that do not, we can conclude that playing *Tetris* causes an improvement in cognitive skills. The design of Study 2 allows for a direct test of the cognitive consequences research question by determining whether the enhanced Tetris group (or even the Tetris group) shows greater improvements in cognitive skills than a control group that does not play the game.

A major hurdle in research on game effectiveness is to determine whether cognitive skills exercised within the game context can transfer to improvements in cognitive skills performed outside the game context, and ultimately in practical contexts such as in school, work, and everyday life. In order to incorporate this thorny issue of transfer in the present study, we administer pretests and posttests on six cognitive skills related to *Tetris* but presented in a context outside of game play: *Tetris* and non-*Tetris* mental rotation, visualization, perceptual speed, useful field of view, and visuospatial working memory. In this way, we seek to determine whether we can develop an enhanced training program with *Tetris* that leads to improvements in transferable cognitive skills.

In short, this study examines the extent to which playing an enhanced version of the classic spatial puzzle game, Tetris will transfer to improvements in spatial and perceptual skills in non-game environments. By transfer, we mean the effects of prior learning (in this case, 4 hours of Tetris playing) on subsequent performance (in this case, performance on classic paper-based and computer-based tests of spatial and perceptual skills). By spatial and perceptual skills, we mean the ability to mentally represent and/or manipulate visual stimuli as measured by the card rotation test, form board test, perceptual speed test, 2-D Tetris rotation test, useful field of view test, and Corsi block-tapping test, as described in the method section of study 1. By non-game environment, we mean that the spatial and perceptual skills are performed on tasks that do not involve playing Tetris.

The major empirical contribution of the current set of studies is to determine whether it is possible to take an off-the-shelf game that was designed for entertainment, and add enhancements that will allow it to serve as a vehicle for improving educationally relevant cognitive skills. The major theoretical contribution of the current set of studies is to explore the nature of transfer of cognitive skills, particularly the thorny issue of how to increases the changes that cognitive skills learned in one domain will result in improvements in another domain.

1.2 Literature Review

Can playing *Tetris* help students improve their cognitive skills? *Tetris* involves rotating and aligning shapes, so on its face it appears to be a good candidate for developing spatial skills like mental rotation, visualization, and perceptual attention. In a recent review of the literature (Mayer, 2014), students who were assigned to play *Tetris* did not show substantially better gains than students who did not play *Tetris* on an array of tests of spatial cognition (median $d = .04$ based on 15 experimental comparisons), perceptual attention (median $d = 0.15$ based on 5 experimental comparisons), or 3-D mental rotation (median $d = 0.22$ based on 3 experimental comparisons). Similarly, *Tetris* playing did not have a strong positive effect on memory tasks ($d = -0.44$, Boot et al., 2008), reasoning tasks ($d = 0.08$ and $d = -0.43$; Boot et al., 2008), or task switching (d = 0.18, Goldstein et al., 1997; d = 0.35, Boot et al., 2008). However, as 2D mental rotation appears to be the most obvious component of *Tetris*, it is interesting to note that playing *Tetris* had a strong positive effect on mental rotation of 2D *Tetris*-like shapes (median d = 0.82 based on 6 comparisons) and a small-to-medium effect on mental rotation of 2D non-*Tetris* shapes (median d = 0.38 based on 5 experimental comparisons). Thus, the only strong and consistent effect reflected in literature is highly specific: playing *Tetris* helps improve mental rotation of shapes like those in the game. These results suggest that the cognitive skills exercised in playing *Tetris* do not appear to transfer to contexts outside of the game.

Given the generally poor showing of off-the-shelf games such as Tetris for improving cognitive skills, it is worthwhile to determine whether they can be repackaged based on cognitive theory to be effective. In short, before declaring Tetris as ineffective in promoting the development of spatial and perceptual skills relevant for education, the current set of studies adds to the literature by determining whether we can add instructional enhancements to Tetris playing than foster transfer of cognitive skills to non-game environments.

1.3 The Elusive Search for Transfer in Computer Games

When students progress through a computer game, such as *Tetris*, they develop in-game knowledge and skills that help them perform well in the game. Is the knowledge that students gain specific to the game context, or can elements of that knowledge be useful in new situations? Although procedural fluency--performing action sequences smoothly without conscious attention--is highly prized in computer game playing, it is not a characteristic typically associated with training transferable skills. Fluency leads to gains during the training of procedural knowledge but does not lead to the transfer of procedural knowledge, such as when training in one skill increases performance in another skill or situation (Schmidt & Bjork, 1992). Game environments therefore offer both opportunities and challenges as educational tools. One such challenge is the focus of this study—what can be added to games to promote cognitive processing that leads to transferable skills?

Diverse attempts to facilitate transfer of cognitive skills trained in computer games to non-game contexts generally have not been made. However, some success has been demonstrated by taking a *contextual interference* approach (Battig, 1972; Shea & Morgan, 1979). For example, research has shown that combining spatial skills training with *Tetris* training improves spatial skill performance better than combining spatial skill training with a non-spatial game (Terlecki, Newcombe, & Little, 2008). This suggests that transferable spatial skills can be developed when in-game practice with a skill is combined with practice of the same skill in a non-game context. The strongest and most well established effect of using computer games to train cognitive skills is the positive effect of playing first-person shooting games on perceptual attention skills (see Mayer, 2014 for a review). These results may be explained by the contextually dynamic nature of first-person shooters: first-person shooters require the player to practice their visual attention skills in an ever-changing context (Green & Bavelier, 2003, 2006).

1.4 Declarative Knowledge as a Basis for Transfer in Skill Learning

Declarative knowledge, such as memory for facts, concepts, or events, involves conscious awareness, whereas procedural knowledge (also called skill knowledge), does not require conscious remembering (Schacter & Tulving, 1994; Squire & Zola, 1996). In general, learned skills are assumed to be highly specific and bound to the context of training (Schacter & Tulving, 1994; Squire & Zola, 1996). Training designed to foster expert skilled performance, such as deliberate practice, leads to outcomes that are specific and automatic (Anderson, 1982; Ericsson & Kintsch, 1995). However, under certain training conditions, transfer can be demonstrated with both simple and complex skills (Singley & Anderson, 1989). Therefore, training must be adapted when the goal is to foster outcomes that are more flexible. Although researchers have been interested in how to train transferable skills for over a century, work is still emerging aimed at principles for training transferable skills (Pellegrino & Hilton, 2012).

Skill learning is characterized by declarative guidance at early stages of learning, and increased automaticity at later stages of learning (Anderson, 1982; Fitts & Posner, 1967; Pellegrino & Hilton, 2012). One proposal for the facilitation of transfer in skill learning is to increase the amount of task-relevant declarative processing the learner performs during learning (Sun, Merrill, & Peterson, 2001; Sun, Slusarz, and Terry, 2005; van Merrienboer, Jelsma, & Paas, 1992), in order to keep the learner in the declarative stage of skill acquisition longer (Hesketh, 1997). This approach to training sets the learner off in the right direction before implicit learning takes over (Sun, Merril, & Peterson, 2001) by taking advantage of the flexibility in interpreting rules afforded by early stages of skill acquisition (Ahlum-Heath & Di Vesta, 1986). This gives learners an opportunity to build a declarative knowledge base including rules and schemas that can be used as a basis for later transfer, allowing them to develop *reflective expertise* (van Merrienboer, Jelsma, & Paas, 1992). Declarative processing also allows the learner to develop metacognitive skills for self-assessment and dealing with errors (Hesketh, 1997). Metacognitive skills represent a form of conditional knowledge, in which learners know when and how to use their declarative and procedural knowledge. In summary of this position, Hesketh (1997) argued that "maximising the chance of developing transferable expertise… requires a lengthening of the time during skill acquisition when analytic processing is involved" (p. 321). This is the approach we take for the enhanced Tetris group training in the present study.

Evidence suggesting that spending more time in the declarative stage of skill acquisition can facilitate transfer began with a seminal study by Charles Judd. Judd (1908) found that subjects who were given a lesson on light refraction improved more quickly on a task throwing darts at underwater targets than those who did not get the lesson. Modern experiments find similar results. For example, in a reaction time task, participants who developed explicit knowledge about the sequence of stimuli demonstrated better transfer than those who did not develop explicit knowledge (Willingham, Nissen, & Bullemer, 1989). A study using the Tower of Hanoi task and Katona card problem found that participants do not spontaneously focus on the process of finding a solution, but when they are forced to do so with explicit prompting to describe their problem-solving process, transfer effects are positive (Berardi-Coletta, Buyer, Dominowski, & Rellinger, 1995). Similarly, participants who verbalized while completing the 3-disk Tower of Hanoi task showed better transfer to the 6-disk Tower of Hanoi task, although the effect was eliminated if participants were first given practice without verbalization (Ahlum-Heath & Di Vesta, 1986). Participants completing a minefield navigation task in a dual task condition that suppressed verbalization showed worse transfer performance than participants in a single task condition (Sun, Merril, & Peterson, 2001). Concurrent and post-task verbalization on concrete version of Wason selection task improved transfer to abstract version of task compared to no verbalization (Berry, 1983). Novice players demonstrated better transfer of a chess endgame when they gave self-explanations of errors during a learning phase (de Bruin, Rikers, Schmidt, 2007).

1.5 Training Spatial Skills

Do principles for training higher-level cognitive skills also apply to training lower-level cognitive skills, such as spatial skills? The idea that spatial skills can be trained in a transferable way is only recently established. While most work shows a high degree of specificity and limited room for transfer in spatial skill learning (Honey & Hilton, 2006; Sims & Mayer, 2002), a recent meta-analysis concludes that spatial skills may be exceptionally malleable. Uttal and colleagues (2013) reviewed the effect of spatial training on transfer and found an overall effect size of $g = 0.48$. That effect size is remarkably substantial considering how elusive transfer effects typically are. While their review did not analyze which experimental factors moderated the transfer effect, the authors speculated that the effect size was large because studies that intend to measure transfer tend to use more heavy-handed manipulations (such as prolonged training regimens) in order to maximize the chances of an effect. Thus, while evidence suggests that spatial skills can be trained in a transferable way, specific theoretical guidelines for doing so have not been established.

1.6 Which Cognitive Skills Are Involved in Playing *Tetris*

Tetris was selected for the current experiments because it is the most studied computer game (Mayer, 2014). While no formal cognitive task analysis of *Tetris* playing has been completed, connections between *Tetris* operations and cognitive operations can be proposed. Some cognitive skills that may be utilized during *Tetris* play are mental rotation (such as when a player needs to know how a piece will be configured when turned to a different orientation), spatial visualization (such as when a player needs to imagine how a piece will fit in with the existing board, what pieces are necessary to clear lines on a board, or what the board could look like several moves ahead), perceptual speed (such as when a player must rapidly scan the shape of each new falling piece and the shape of the ever-changing board configuration), useful field of view (such as noticing when a new shape has appeared, noticing the configuration of the board, and noticing the next shape in the line-up), and visuospatial working memory (such as imagining how an object will rotate while maintaining a mental representation of the configuration of the board).

The game mechanics of *Tetris* allow a player to offload some mental effort through onscreen actions. For example, a player can offload the cognitive effort required by mental rotation by pressing a key on the keyboard to rotate the shape on the screen. Kirsh and Maglio (1994) use the term *epistemic action* to refer to onscreen rotations intended to reduce the need for mental operations. For example, a player may use rotations beyond what is necessary to get a piece into position. These moves can appear superfluous, but they serve a purpose by obviating effortful mental rotation processes. In contrast to epistemic actions are *pragmatic actions*, which are onscreen rotations meant to get players closer to their in-game goals. *Tetris* players can use a combination of mental rotation, epistemic onscreen rotations, and pragmatic onscreen rotations strategically during play. Players with greater skill in *Tetris* are more likely than lower-skilled players to use epistemic actions (Maglio & Kirsh, 1996). Advanced *Tetris* players may also use game mechanics to assist with some of the perceptual requirements of *Tetris*, such as rotating pieces as soon as they appear in order to help identify their shape (Kirsh & Maglio, 1994; Maglio & Kirsh, 1996). Thus, players may develop techniques while playing *Tetris* that minimize the need to engage in spatial skills such as mental rotation.

2. Study 1 (Value Added Study)

Overall, the literature does not support the conclusion that Tetris is an effective vehicle for improving cognitive skills, but before giving up on Tetris, the objective of the present study was to determine whether the effectiveness of playing Tetris could be improved by adding enhancements aimed at helping learners reflect on the cognitive processing involved. Specifically, the goal of the present study is to investigate the effect of adding declarative practice with *Tetris* problem-solving to *Tetris* training on the transfer of spatial skills to contexts outside of game play (i.e., performance on computer- and paper-based tests of spatial and cognitive skills). The training program designed for this purpose is similar to cognitive apprenticeship programs (Bloom & Broder, 1950; Collins, Brown, & Holum, 1991) or worked examples (Renkl, 2011, 2014). In both of these training contexts, an expert gives novice learners guidance on how to perform a task with a particular focus on the expert's thought processes. Our training program focuses on helping participants reflect on strategies that will help them play *Tetris* successfully. The training required participants to practice *Tetris* with a focus on planning and visualization skills in simulated game situations. The goal of this experiment is to facilitate specific transfer of general skills, that is, to help learners apply the skills practiced while playing *Tetris* to non-game contexts that require the same skills. This type of transfer is *specific* in that it only the skills practiced in the game are improved, and *general* in that those skills can be applied in multiple situations. The main question addressed in Study 1 is: Can adding modeling that encourages participants to play *Tetris* in a more reflective way help participants transfer skills learned in *Tetris* to new situations?

According to the training hypothesis, training in reflecting on the processes underlying gameplay is proposed to promote specific transfer of general skills learned in playing *Tetris*. Therefore, participants who receive model-based training alongside practice playing *Tetris* are predicted to show greater gains in the cognitive skills required by *Tetris* in non-game contexts than students who practice playing *Tetris* alone.

2.1 Method

2.1.1 Participants and design. The participants were 59 undergraduate students (12 men, 47 women) from [deleted for masked review] recruited through the Paid Psychology

Subject Pool and through signs posted in the Psychology building. Participants were required to be non-video game players, which was defined as playing less than one hour per week of any type of video game. Non-video game players were chosen in order to reduce the effect of prior experience, and to select participants who could easily refrain from video game play outside the laboratory during the course of the experiment. Participants received $10/hour in compensation for their participation. Twenty-nine participants served in the enhanced Tetris condition, and 30 served in the Tetris only condition.

2.1.2 Materials.

2.1.2.1 Game. *Meta-T* is a highly configurable version of the classic arcade game *Tetris* (Lindstedt & Gray, 2013). Figure 1 shows a screenshot of the game. Shapes made up of four square blocks fall from the top of the screen at a steady rate into a game area 10 blocks wide and 20 blocks high. The player uses the arrow keys on a standard keyboard to rotate the shapes clockwise or counterclockwise (counterclockwise rotation requires holding the shift key while pressing the up arrow) and to move the shapes left and right to control where they fall. The player must place the shapes efficiently, as leaving spaces between blocks causes the screen to fill up with blocks. When a horizontal row is filled with blocks, that line disappears and any blocks above that row fall down as a group. Multiple rows can be cleared at once if more than one row is completed with the placement of a single shape. The game level increases for every 10 rows cleared. The shapes fall with increasing speed as level increases. The game ends when the stack of blocks hits the top of the screen. The *Meta-T* software collects highly granular data on game play and strategy, including the number of rotations and translations (i.e., movements right and left) a player uses for each block and a frame-by-frame record of the board configuration.

2.1.2.2 Lessons and worksheets. Four lessons on problem-solving in *Tetris* were developed, as well as corresponding worksheets. The lessons were designed similarly to a worked-out example. Participants first watched a video slideshow with audio narration of an expert describing the way she would complete a *Tetris* problem-solving task (see Figure 2). The expert described her thought process as she completed each move. For example, the expert demonstrated how to think ahead about what types of board configurations allow more flexibility in future movements. Each video slideshow took between four and five minutes to watch.

At the end of the lesson, participants were given an instruction sheet (see Figure 3) and a worksheet with an in-progress *Tetris* board and four *Tetris* shapes (see Figure 4). The problem was similar in complexity and required strategy as the example just viewed, although the given board and available shapes were not identical. The instruction sheet directed participants to use the four shapes in any order to fill in the board as efficiently as possible, instructed the participant to show their work, and gave a worked example of showing work. Participants were given five minutes to complete the worksheets.

2.1.2.3 Cognitive tests. There were pre-training and post-training versions of each of the cognitive tests. Three paper-based tests were administered: a card rotation test, a form board test, and a test of perceptual speed. Three computer-based tests were administered: a 2-D *Tetris* rotations task, a useful field of view task, a visuospatial working memory task.

2.1.2.3.1 Card rotation test. The card rotation test is a 2-D mental rotation test from Educational Testing Service (Ekstrom et al., 1976). A target figure is presented to the left of a line, and 8 figures are presented to the right of the line. The figures at the right of the line are either the same as the figure at the left, but rotated around in the picture plane, or they are different, in that they are mirror-reversed versions of the figure at the left. Participants were given 3 minutes to make 80 same/different judgments for different figures on the pre-training and post-training tests. This test is intended to tap mental rotation processing, which appears to be required to rotate *Tetris* shapes in the game.

2.1.2.3.2 Form board test. The form board test was also from Educational Testing Service (Ekstrom et al., 1976), and requires participants to decide what combination of five smaller shapes can be combined to form a final shape. Any number of smaller shapes, from two to five, can be used to complete the final shape. Participants were given 8 minutes to complete 24 items on the pre-training and post-training tests. This test is intended to tap the ability to visualize how shapes will fit together, which appears to be required to determine where to place *Tetris* shapes in order to clear a row.

2.1.2.3.3 Perceptual speed test. The perceptual speed test is the number comparison test from Educational Testing Service (Ekstrom et al., 1976). Participants see a two-column list with a space in between the columns. If the numbers on either side of the space are the same, participants do nothing. If the numbers are different, participants mark the space with an X. Participants were given 90 seconds to make 48 comparisons on the pre-training and post-training tests. This test is intended to tap the ability to quickly recognize on-screen objects, as appears to be required in *Tetris.*

2.1.2.3.4 2-D Tetris rotations. The 2-D Tetris rotations task included four Tetris shapes (S, Z, L, and J pieces) and four Tetris-like shapes. Participants see a base shape and a shape that is either the same, just rotated around in the picture plane, or flipped and rotated. Participants use arrow keys to indicate whether the two shapes are the same or different. Participants completed 2 practice trials and 112 test trials. The pre-training test was identical to the post-training test, except for the order of trials, which was randomized. The test was administered through DirectRT. This test taps skill in mental rotation that appears to be needed in *Tetris.*

2.1.2.3.5 Useful field of view (UFOV) test. The UFOV test requires participants to identify the radial location of a rapidly-flashed target followed by a visual mask. The target could occur at one of 8 radial locations, at three distances from the fixation point at the center of the screen. The target could therefore appear in one of 24 onscreen positions. The participant used the keyboard number pad to indicate the direction from the center that the target occurred. In the no-distractor block the target is presented alone for 16.7 ms. In the distractor block the target is presented in an array of distractors for 33.3 ms. The display times for the distractor and non-distractor block were determined following pilot testing in order to avoid ceiling or floor effects. Display times were constrained by the refresh rate of the computer monitors (16.7 ms frame duration; 60 Hz refresh rate).

In a typical UFOV task the visual angle of the targets is tightly controlled (usually 10, 20, and 30 degrees away from fixation) by providing participants with a chin rest close to the screen. In this experiment, participants were not given a chin rest. Participants were instructed to tuck their chair in, sit up, and not lean toward or away from the screen for this task. The monitors were placed in the same position on the desk for each participant. For a research assistant who is 5’6” tall and following task instructions, the three levels of visual angle were 5°, 10°, and 15° from fixation. Visual angle varied among participants based on their specific height, posture, and sitting position. The pre-training test was identical to the post-training test, except for the order of trials, which was randomized in blocks. The test was administered through DirectRT. This test skill in recognizing perceptual objects in the periphery, which may be needed in *Tetris* when looking between a falling object and where it will fit in the bottom of the screen

2.1.2.3.6 Corsi block-tapping test. For the test of visual working memory capacity, the Corsi block-tapping task was used. In this task a staggered array of nine colored squares is displayed. A sequence of squares lights up, and participants click on the squares to repeat the sequence. Participants complete two practice trials followed by twelve test trials: two trials per sequence length starting with three squares and continuing to eight squares. This test was administered through Psychology Experiment Building Language (PEBL; Mueller & Piper, 2014). Being able to keep track of visual objects appears to be a skill that also is required in *Tetris.*

2.1.2.4 Questionnaire. A questionnaire asked participants to indicate demographic information: age, gender, year in school, and major. It also asked participants to indicate their video game experience with the question, "How many hours a week do you typically play video games?," followed by the response options, "More than 10 hours per week," "5 to 10 hours per week," "1 to 5 hours per week," "less than 1 hour per week," and "I do not play video games." A final item asked, "Have you ever played Tetris before? Y/N."

2.1.3 Procedure. The experiment was completed over the course of 6 sessions. In the first session, participants completed a consent form and questionnaire, and then completed the pre-training version of the six cognitive tests in the following order: card rotation test, number comparison test, form board test, Corsi block-tapping test, Tetris mental rotation test, and UFOV test. They then played a game of *Meta-T* with the instructions to try to get as high of a score as possible. Participants who lost their first game of *Meta-T* in less than five minutes were instructed to play a second game. For the participants who played two games, their highest score was used as their pre-training high score.

In the subsequent four sessions, participants in the enhanced Tetris group first watched the slideshow and then completed a worksheet. The slideshow took approximately four minutes to watch and participants were given 5 minutes to complete the worksheet. After completing the worksheet participants were given one minute to compare their completed worksheet to an efficiently solved worksheet. They then played *Meta-T* for the remainder of an hour. Participants in the Tetris only group played *Meta-T* for a full hour.

In the final session, participants completed the post-training version of the six cognitive tests. They then played a game of *Meta-T* with the instructions to try to get as high of a score as possible. Participants who lost their first game of *Meta-T* in less than five minutes were instructed to play a second game. For the participants who played two games, their highest score was used as their post-training high score.

2.2 Results

2.2.1 Data source. If a participant missed any session they were instructed not to return for subsequent sessions. Of the 59 participants who started the experiment, 49 completed all six sessions. As a result, 24 participants remained in the enhanced Tetris group and 25 participants remained in the Tetris-only group. There was not a significant difference between groups in number of eliminated participants, $X^2(N = 59) = 0.003$, $p = .95$. All subsequent analyses refer to this subset of participants.

2.2.2 Are the groups equivalent on basic characteristics? A preliminary step is to determine whether the groups are equivalent on basic demographic characteristics. The two groups were compared for differences on age, proportion of men and women, time spent playing video games per week, and *Tetris* performance on day 1. An independent samples *t*-test revealed no difference between the groups on age $t(47) = 0.16$, $p = 0.88$. A chi-square test found no significant differences between the groups on proportion of men and women, X^2(N = 49) = 0.004, *p* = .95. A Kruskal-Wallis H test revealed no significant difference between groups on time spent playing video games per week, X^2(N = 48) = 0.026, *p* = .87. A chi-square test revealed a significant difference between groups in having previously played *Tetris*, X^2(N = 49) = 4.22, *p* = .04, with 2 participants in the enhanced Tetris condition who had never played *Tetris* before, compared to 8 participants in the Tetris only group. Thus, the groups did not differ on basic characteristics, except for the proportion of participants who had never played *Tetris*. To equate the groups on pre-existing skills, we use pretest score as a covariate in all statistical comparisons.

2.2.3 Does training affect gains in cognitive skills? Descriptive statistics for pre-training and post-training performance on each of the cognitive skills tests are reported in Table 1. The two groups were compared for pretest-to-posttest differences on the cognitive skills tests. Individual ANCOVAs for each skill used pre-training performance as a covariate and pre-training to post-training gains as the outcome variable. If the training hypothesis is supported, participants in the enhanced Tetris group would demonstrate greater gains on the measures of cognitive skills.

2.2.3.1 Card rotation test. Scores on the card rotation test were determined by subtracting the number of incorrect responses form the number of correct responses. Incorrect responses were responses that were marked incorrectly, not blank responses. There was no significant difference in pre-training to post-training gains on the card rotation test between the enhanced Tetris group (*M* = 6.45, *SD* = 14.53) and the Tetris only group (*M* = 9.84, *SD* = 13.72) when controlling for pre-training performance (effect of covariate: $F(1,46) = 35.74$, $p < 0.001$;

effect of condition: $F(1,46) = 0.33$, $p = 0.57$). These results indicate that enhanced Tetris training did not improve card rotation performance compared to the Tetris only condition.

2.2.3.2 Form board test. Scores on the form board test were determined by the number of complete correct problems (i.e., all five response items in a problem had to be marked correctly; 24 possible). There was no significant difference in pre-training to post-training gains on the form board test between the enhanced Tetris group ($M = 1.54$, $SD = 6.76$) and the Tetris only group ($M = 0.16$, $SD = 4.78$) when controlling for pre-training performance (effect of covariate: $F(1,46) = 16.83$, $p < 0.001$; effect of condition: $F(1,46) = 0.08$, $p = 0.77$). These results indicate that that enhanced Tetris training did not improve form board performance compared to the Tetris only condition.

2.2.3.3 Perceptual speed test. Scores on the perceptual speed test were determined by the number of correct responses (i.e., lines checked or left blank that should have been checked or left blank, respectively) minus the number of incorrect responses (i.e., lines checked or left blank that should have been left blank or checked, respectively). There was no significant difference in pre-training to post-training gains on perceptual speed test between the enhanced Tetris group ($M = 4.50$, $SD = 5.08$) and the Tetris only group ($M = 4.56$, $SD = 7.25$) when controlling for pre-training performance (effect of covariate: $F(1,46) = 9.17$, $p = 0.004$; effect of condition: $F(1,46) = 0.45$, $p = 0.50$). These results indicate that enhanced Tetris training did not improve perceptual speed performance compared to the Tetris only condition.

2.2.3.4 2-D Tetris rotations. 2-D Tetris rotation performance was scored on both overall accuracy (i.e., number of correct responses divided by number of total responses) and overall reaction time (i.e., average reaction time across rotation angles in milliseconds). There was no significant difference in pre-training to post-training gains on 2-D Tetris rotation accuracy between the enhanced Tetris group (*M* = 0.003, *SD* = 0.03) and the Tetris only group (*M* = -0.001, *SD* = 0.03) when controlling for pre-training performance (effect of covariate: $F(1,46) = 4.39$, $p = 0.042$; effect of condition: $F(1,46) = 0.31$, $p = 0.58$). There was no significant difference in pre-training to post-training gains on 2-D Tetris rotation reaction time between the enhanced Tetris group (*M* = -584.10, *SD* = 490.00) and the Tetris only group (*M* = -512.48, *SD* = 516.39) when controlling for pre-training performance (effect of covariate: $F(1,46) = 61.43$, $p < 0.001$; effect of condition: $F(1,46) = 0.33$, $p = 0.57$). These results indicate that enhanced Tetris training did not improve overall accuracy or reaction time on the 2-D Tetris mental rotation test compared to the Tetris only condition.

Further analyses were conducted to determine if Tetris mental rotation strategies differed between groups. Performance on this task was analyzed for slope (i.e., average increase in reaction time divided by increase in angle of disparity) and intercept (i.e., value of the rotation function when degree of angular disparity is 0) for each participant. Lower slopes correspond to faster rates of mental rotation, and lower intercepts correspond to other cognitive processing such as faster encoding and comparison of the stimuli, and/or faster initiation of a response. There was no significant difference in pre-training to post-training gains on 2-D Tetris rotation slope (ms/degree) between the enhanced Tetris group (*M* = -3.48, *SD* = 7.10) and the Tetris only group (*M* = -2.80, *SD* = 4.23) when controlling for pre-training performance (effect of covariate: $F(1,46) = 94.96$, $p < 0.001$; effect of condition: $F(1,46) = 1.62$, $p = 0.21$). There was no difference in pre-training to post-training gains on 2-D Tetris rotation intercept (ms) between the enhanced Tetris group (*M* = -199.48, *SD* = 200.21) and the Tetris only group (*M* = -219.43, *SD* = 429.10) when controlling for pre-training performance (effect of covariate: $F(1,46) = 101.31$, $p < 0.001$; effect of condition: $F(1,46) = 1.96$, $p = 0.17$). These results indicate that enhanced Tetris training did not improve 2-D Tetris mental rotation strategy compared to the Tetris only condition.

2.2.3.5 Useful field of view (UFOV) test. Scores on the UFOV test were determined by the overall accuracy (correct responses divided by total responses) including both the distractor absent and distractor present trials. There was no significant difference in pre-training to post-training gains on the UFOV test between the enhanced Tetris group (M = 3.62, SD = 9.90) and the Tetris only group (M = 2.60, SD = 9.20) when controlling for pre-training performance (effect of covariate: $F(1,46) = 21.73$, $p < 0.001$; effect of condition: $F(1,46) = 0.11$, $p = 0.97$). These results indicate that enhanced Tetris training did not improve UFOV performance compared to the Tetris only condition.

2.2.3.6 Corsi block-tapping test. Scores on the Corsi block-tapping test were determined by the total number of correct responses in the correct serial order across trials. There was a significant difference in pre-training to post-training gains on the Corsi block-tapping test between the enhanced Tetris group (M = 0.83, SD = 7.15) and the Tetris only group (M = 3.68, SD = 6.94) when controlling for pre-training performance (effect of covariate: $F(1,46) = 23.45$, $p < 0.001$; effect of condition: $F(1,46) = 7.03$, $p = 0.011$), in which the Tetris only group showed greater gains on the Corsi block-tapping test than the enhanced Tetris group. In this case, enhanced Tetris training did not improve Corsi block-tapping performance compared to the Tetris only condition.

2.2.4 Does training affect Tetris performance? The two groups were compared for their pre-training to post-training gains on several indicators of *Meta-T* performance. Individual ANCOVAs for each indicator of Tetris performance used pre-training performance as a covariate and pre-training to post-training gains as the outcome variable. If the training improves *Tetris* performance, then participants in the enhanced Tetris group will achieve higher overall performance, as evidenced by their final score, and demonstrate higher efficiency in their game play, as evidenced by fewer unnecessary rotations and translations of *Tetris* pieces, which are recorded with the in-game measures in *Meta-T*. There was no significant difference in pre-training to post-training gains on Tetris high score between the enhanced Tetris group (M = 12191.46, SD = 7705.76) and the Tetris only group (M = 16296.48, SD = 18136.17) when controlling for pre-training performance (effect of covariate: $F(1,46) = 0.332$, $p = 0.57$; effect of condition: $F(1,46) = 1.06$, $p = 0.31$). There was no significant difference in pre-training to post-training gains on Tetris efficiency (i.e., average number of unnecessary rotations and translations per piece) between the enhanced Tetris group (M = -0.33, SD = 0.57) and the Tetris only group (M = -0.51, SD = 1.16) when controlling for pre-training performance (effect of covariate: $F(1,46) = 4.14$, $p = 0.048$; effect of condition: $F(1,46) = 0.25$, $p = 0.62$). Enhanced Tetris training did not improve Tetris performance in high score or efficiency compared to the Tetris only condition.

2.3 Discussion

In this experiment, participants completed four training sessions that consisted either of playing only *Tetris* (Tetris only group), or playing *Tetris* plus going through lessons and worksheets designed to help them reflect on the skills used in the game (enhanced Tetris group). Pre-training and post-training tests measured performance on relevant cognitive skills. Analyses revealed no benefit of training on any of the cognitive skills tested. These results do not support the training hypothesis, as giving participants enhanced training that focused on reflecting on the skills used in *Tetris* did not increase their gains in cognitive skills compared to a group that only played *Tetris*. This experiment is novel in the way it takes a value-added approach to investigating the effect of computer games on cognitive skills, rather than the usual cognitive consequences approach. This approach allows researchers to take a controlled, theory-driven approach to asking questions about the effects of playing computer games on cognitive skills. This experiment is also novel in adding cognitive modeling, an approach in which an expert explains their thought processes to a novice, to computer-game training. This method has been successful in training cognitive skills in other contexts such a problem solving (Bloom & Broder, 1950). Overall, this experiment adds to the limited research base on the effects of playing computer games on spatial and cognitive skills.

The results of this experiment also have theoretical implications. The features that characterize games contribute to an immersive, fluent experience. However, fluency in training procedural knowledge does not necessarily lead to the transfer of that knowledge. The goal of the intervention in this experiment was to increase participants' declarative knowledge base about the skills used in *Tetris*, thus providing a stronger basis for transfer. This experiment does not provide support for the idea that increasing one's declarative knowledge base about a spatial or cognitive skill will increase the likelihood of transfer of that skill. Study 2 is intended to investigate whether there is any effect of the *Tetris* training (either enhanced Tetris or Tetris only) on gains on the target skills compared to an inactive control group.

3. Study 2 (Cognitive Consequences Study)

In Study 1, there was no benefit of the enhanced Tetris training compared to the Tetris only training on any of the 6 cognitive tests. Given the lack of effectiveness in adding enhancements to Tetris in Study 1, a reasonable next question is whether either of the groups in Study 1 showed improvements in cognitive skills. Study 2 addresses this question by comparing the pretest-to-posttest gains of the groups in Study 1 versus a control group that does not play games. Specifically, in Study 2, an inactive control group was added that took both the pre-training tests and the post-training tests, but did not play *Tetris* or receive any training in between. This experiment investigates whether there was an effect of playing *Tetris* – in either the enhanced training condition or the Tetris only condition – on any of the skills tested.

3.1 Method

3.1.1 Participants and design. The participants were 25 undergraduate students (11 male, 14 female) from [deleted for masked review] recruited through the Paid Psychology Subject Pool (which is the same as in Study 1). Participants were required to be non-video game players, which was defined as playing less than one hour per week of any type of video game. Participants received $10/hour in compensation for their participation. All participants in Study 2 served in the inactive control condition.

3.1.2 Materials.

3.1.2.1 Game. The game used in this experiment was the same version of *Meta-T* used in Study 1.

3.1.2.2 Cognitive tests. The pre-training and post-training tests used in this experiment were the same as those used in Study 1: card rotation, form board, perceptual speed, 2-D Tetris rotations, useful field of view, and Corsi block-tapping.

3.1.2.3 Questionnaire. The same questionnaire was used as in Study 1.

3.1.3 Procedure. The experiment was completed over the course of 2 sessions. The first session was the same as the first session of Study 1: participants completed a consent form, a questionnaire, and a series of cognitive tests.

Unlike Study 1, there were no laboratory sessions in between the first and final session.

The second (and final) session took place five weeks after the first session, in order the match the interval between the first and final sessions in Study 1. The second session was the same as the sixth session of Study 1: participants took a series of cognitive tests and then played *Meta-T.*

3.2 Results

3.2.1 Data source. If a participant did not return for the second session their data were excluded from the analyses. Of the 25 participants who started the experiment, 17 completed both sessions. All subsequent analyses refer to this subset of participants as the inactive control group. This group is compared against the enhanced Tetris and Tetris only groups from Study 1. Comparing these three groups required comparing across Study 1 and 2. Although participants were recruited separately for these two experiments, the participants were all recruited from the same Paid Psychology Subject Pool with advertisements that used the same wording except for the number of sessions specified (6 sessions in Study 1, 2 sessions in Study 2). The procedure for the two sessions of Study 2 was identical to the first and sixth sessions of Study 1, and participants from both experiments were instructed not to play video games outside of the laboratory for the duration of the experiment. These steps were taken in order to minimize the likelihood of population differences between the two experiments. The subsequent two sections test for differences among the groups on basic characteristics and pre-training task performance.

3.2.2 Are the groups equivalent on basic characteristics? A preliminary step is to determine whether the participants in Study 2 are equivalent to the participants in Study 1 on basic demographic characteristics. The groups were compared for differences on age, proportion of men and women, time spent playing videogames per week, and Tetris performance on day 1. An ANOVA revealed no significant difference between the groups on age $F(2,63) = 1.23$, $p =$

0.30. A chi-square test found no significant differences between the groups on proportion of men and women, X^2(N = 66) = 2.72, p = 0.26. A Kruskal-Wallis H test revealed a significant difference between groups on time spent playing video games per week, X^2(N = 65) = 6.96, p = .03, with the inactive control group having a higher mean rank (M = 23.29) than the enhanced Tetris (M = 36.80) or Tetris only groups (M =36.10). No participants in the inactive control group indicated playing more than one hour of video games per week, which was the criterion for inclusion in the experiment. A chi-square test revealed no difference between groups in having previously played *Tetris*, X^2(N = 66) = 4.18, p = .14. These results indicate that the groups were not different on basic characteristics, except for amount of video game play each week.

3.2.3 Are the groups equivalent on pre-training task performance? A further step taken to justify the comparing the participant sample from Study 1 to the sample from Study 2 is to test whether participants Study 2 are equivalent to the participants in Study 2 on pre-training performance. ANOVAs revealed no significant difference between the groups on pre-training performance for the card rotation test, F(2,63) = 2.07, p = 0.14, form board test, F(2,63) = 2.15, p = 0.13, perceptual speed test, F(2,63) = 1.05, p = 0.35, 2-D Tetris mental rotation accuracy, F(2,63) = 0.35, p = 0.70, useful field of view test, F(2,63) = 12.39, p = 0.10, or Corsi block-tapping test, F(2,63) = 2.18, p = 0.12. There was a marginal difference between the groups on Tetris mental rotation reaction time, F(2,63) = 2.48, p = 0.09. These results indicate that the groups were not different on pre-training performance, except for a marginal difference in Tetris mental rotation reaction time. As with the analyses of Study 1, all subsequent analyses of pre-training to post-training gains include pre-training performance as a covariate.

3.2.4 Does training affect gains in cognitive skills? Descriptive statistics for pre-training and post-training performance on each of the cognitive skills tests are reported in Table 1. The three groups were compared for differences on pretest-to-posttest gains on the cognitive skills tests. Individual ANCOVAs for each skill used pre-training performance as a covariate and pre-training to post-training gains as the outcome variable. All tests were scored in the same manner as Study 1.

3.2.4.1 Card rotation test. There was a significant difference in pre-training to post-training gains on the card rotation test between the inactive control group (M = 10.23, SD = 13.39), the enhanced Tetris group (M = 6.45, SD = 14.53), and the Tetris only group (M = 9.84, SD = 13.72) when controlling for pre-training performance (effect of covariate: $F(1,62) = 57.21$, $p < 0.001$; effect of condition: $F(2,62) = 3.33$, $p = 0.042$). A Bonferonni-corrected posthoc analysis revealed that the inactive control group showed greater gains on the test than the enhanced Tetris group ($M_{diff} = 8.23$, SE = 3.27, $p = 0.043$). No other group comparisons were significant ($\alpha = 0.05$). These results indicate that there was no benefit of either type of Tetris training on card rotation gains, with the inactive control group significantly outperforming the enhanced Tetris group.

3.2.4.2 Form board test. There was no significant difference in pre-training to post-training gains on the form board test between the inactive control group (M = 0.12, SD = 3.64), the enhanced Tetris group (M = 1.54, SD = 6.76) and the Tetris only group (M = 0.16, SD = 4.78) when controlling for pre-training performance (effect of covariate: $F(1,62) = 16.38$, $p < 0.001$; effect of condition: $F(2,62) = 0.15$, $p = 0.86$). These results indicate that playing Tetris did not improve form board performance.

3.2.4.3 Perceptual speed test. There was a significant difference in pre-training to post-training gains on the perceptual speed test between the inactive control group (M = 9.06, SD = 6.41), the enhanced Tetris group (M = 4.50, SD = 5.08), and the Tetris only group (M = 4.56, SD = 7.25) when controlling for pre-training performance (effect of covariate: $F(1,62) = 10.46$, p = 0.002; effect of condition: $F(2,62) = 3.98$, p = 0.024). A Bonferonni-corrected posthoc analysis revealed that the inactive control group showed greater gains on the test than the enhanced Tetris group (M_{diff} = 5.10, SE = 1.87, p = 0.025), and marginally greater gains than the Tetris only group (M_{diff} = 4.05, SE = 1.86, p = 0.099). The difference between the two Tetris training groups was not significant (α = 0.05). These results indicate that there was no benefit of either type of Tetris training on perceptual speed gains, with the inactive control group significantly outperforming the enhanced Tetris group.

3.2.4.4 2-D Tetris rotations. There was no significant difference in pre-training to post-training gains on 2-D Tetris rotation accuracy between the inactive control group (M = -0.01, SD = 0.04), enhanced Tetris group (M = 0.003, SD = 0.03), and the Tetris only group (M = -0.001, SD = 0.03) when controlling for pre-training performance (effect of covariate: $F(1,62) = 7.97$, p = 0.006; effect of condition: $F(2,62) = 0.43$, p = 0.66). There was no difference in pre-training to post-training gains on 2-D Tetris rotation reaction time between the inactive control group (M = 402.13, SD = 531.45), enhanced Tetris group (M = -584.10, SD = 490.00) and Tetris only group (M = -512.48, SD = 516.39) when controlling for pre-training performance (effect of covariate: $F(1,62) = 118.12$, $p < 0.001$; effect of condition: $F(2,62) = 1.03$, p = 0.36). These results indicate that playing Tetris did not improve 2-D Tetris mental rotation accuracy or reaction time.

3.2.4.5 Useful field of view (UFOV) test. There was no difference in pre-training to post-training gains on the UFOV test between the inactive control group (M = 0.00, SD = 10.81), the enhanced Tetris group (*M* = 3.62, *SD* = 9.90), and the Tetris only group (*M* = 2.60, *SD* = 9.20), when controlling for pre-training performance (effect of covariate: $F(1,62) = 22.82$, $p < 0.001$; effect of condition: $F(2.62) = 0.002$, $p = 0.998$). These results indicate playing Tetris did not improve UFOV performance.

3.2.4.6 Corsi block-tapping test. There was a significant difference in pre-training to post-training gains on the Corsi block-tapping test between the inactive control group (*M* = -0.71, *SD* = 6.59), the enhanced Tetris group (*M* = 0.83, *SD* = 7.15), and the Tetris only group (*M* = 3.68, *SD* = 6.94) when controlling for pre-training performance (effect of covariate: $F(1,62) = 30.89$, $p < 0.001$; effect of condition: $F(2,62) = 3.71$, $p = 0.03$). A Bonferonni-corrected posthoc analysis revealed that the Tetris only group showed greater gains on the test than the enhanced Tetris group ($M_{\text{diff}} = 5.10$, $SE = 1.87$, $p = 0.025$). No other group comparisons were significant ($\alpha = 0.05$). The Tetris only group showed greater gains on the Corsi block-tapping test than the enhanced Tetris group. Playing Tetris did not result in improvements on the Corsi block-tapping task compared to the inactive control group.

3.2.5 Does training affect Tetris performance? There was a significant difference in pre-training to post-training gains on Tetris high score between the inactive control group (*M* = 5940.35, *SD* = 14244.39), the enhanced Tetris group (*M* = 12191.46, *SD* = 7705.76), and the Tetris only group (*M* = 16296.48, *SD* = 18136.17) when controlling for pre-training performance (effect of covariate: $F(1,62) = 2.51$, $p = 0.12$; effect of condition: $F(2,62) = 3.44$, $p = 0.038$). A Bonferonni-corrected post-hoc analysis revealed that the Tetris only group showed greater gains on the test than the inactive control group ($\mathrm{M}_{\text{diff}} = 11679.11$, SE = 4456.01, $p = 0.033$). No other group comparisons were significant ($\alpha = 0.05$). There was no difference in pre-training to post-training gains on Tetris efficiency (i.e., average number of unnecessary rotations and translations per piece) between the inactive control group (*M* = -0.15, *SD* = 0.60) enhanced Tetris group (*M* = -0.33, *SD* = 0.57), the Tetris only group (*M* = -0.51, *SD* = 1.16) when controlling for pre-training performance (effect of covariate: $F(1,62) = 10.08$, $p = 0.002$; effect of condition: $F(2,62) = 0.47$, $p = 0.63$). These results indicate that the Tetris only group improved their Tetris score significantly more than the inactive control group. There was no difference in gains between the group in Tetris efficiency.

3.2.6 Do the combined Tetris groups differ from the inactive control group? In order to test whether there was an overall effect of Tetris training compared to the inactive control group, additional analyses were conducted with the enhanced Tetris and Tetris only groups combined to form a combined Tetris group. The combined Tetris group (N = 49) and inactive control group (N = 17) were compared for differences on the cognitive skills tests and on Tetris performance. Individual ANCOVAs for each skill used pre-training performance as a covariate and pre-training to post-training gains as the outcome variable.

3.2.6.1 Card rotation test. There was a significant difference in pre-training to post-training gains on the card rotation test between the inactive control group (*M* = 10.23, *SD* = 13.39) and the combined Tetris group (*M* = 8.18, *SD* = 14.08), when controlling for pre-training performance (effect of covariate: $F(1,63) = 58.81$, $p < 0.001$; effect of condition: $F(1,63) = 6.47$, $p = 0.014$). These results indicate that there was no benefit of Tetris training on card rotation gains, with the inactive control group significantly outperforming the combined Tetris group.

3.2.6.2 Form board test. There was no significant difference in pre-training to post-training gains on the form board test between the inactive control group (*M* = 0.12, *SD* = 3.64), the combined Tetris group (*M* = 0.84, *SD* = 5.82) when controlling for pre-training performance (effect of covariate: $F(1,63) = 17.45$, $p < 0.001$; effect of condition: $F(1,63) = 0.13$, $p = 0.72$). These results indicate that playing *Tetris* did not improve form board performance.

3.2.6.3 Perceptual speed test. There was a significant difference in pre-training to post-training gains on the perceptual speed test between the inactive control group ($M = 9.06$, $SD = 6.41$) and the combined Tetris group ($M = 4.53$, $SD = 6.22$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 10.19$, $p = 0.002$; effect of condition: $F(1,63) = 7.66$, $p = 0.007$). These results indicate that there was no benefit of Tetris training on perceptual speed gains, with the inactive control group significantly outperforming the combined Tetris group.

3.2.6.4 2-D Tetris rotations. There was no significant difference in pre-training to post-training gains on 2-D Tetris rotation accuracy between the inactive control group ($M = -0.01$, $SD = 0.04$) and combined Tetris group ($M = 0.00$, $SD = 0.03$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 7.95$, $p = 0.006$; effect of condition: $F(1,63) = 0.56$, $p = 0.46$). There was no difference in pre-training to post-training gains on 2-D Tetris rotation reaction time between the inactive control group ($M = -402.13$, $SD = 531.45$) and the enhanced Tetris group ($M = 547.56$, $SD = 499.68$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 119.56$, $p < 0.001$; effect of condition: $F(1,63) = 1.68$, $p = 0.20$). These results indicate that playing Tetris did not improve 2-D Tetris mental rotation accuracy or reaction time.

Further analyses were conducted to determine if Tetris mental rotation strategies differed between groups. The same 8 models of Tetris mental rotation strategies were tested as in the analysis of all three groups. A chi-square test revealed no significant differences among the groups on best fit mental rotation strategy for pre-training performance, $X^2(\mathrm{N} = 66) = 5.47$, $p = 0.60$, or post-training performance, $X^2(\mathrm{N} = 66) = 5.80$, $p = 0.33$. These results suggest that there was no significant difference among groups in the way participants performed mental rotation of Tetris objects before or after training.

3.2.6.5 Useful field of view (UFOV) test. There was no difference in pre-training to post-training gains on the UFOV test between the inactive control group ($M = 3.10$, $SD = 9.46$) and the combined Tetris group ($M = 3.62$, $SD = 9.90$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 23.36$, $p < 0.001$; effect of condition: $F(1,63) = 0.003$, $p = 0.96$). These results indicate playing *Tetris* did not improve UFOV performance.

3.2.6.7 Corsi block-tapping test. There was no difference in pre-training to post-training gains on the Corsi block-tapping test between the inactive control group ($M = -0.71$, $SD = 6.59$) and the combined Tetris group ($M = 1.92$, $SD = 7.20$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 25.83$, $p < 0.001$; effect of condition: $F(1,63) = 0.09$, $p = 0.76$). Playing Tetris did not result in improvements on the Corsi block-tapping task compared to the inactive control group.

3.2.6.8 Tetris performance. There was a significant difference in pre-training to post-training gains on Tetris high score between the inactive control group ($M = 5940.35$, $SD = 14244.39$) and the combined Tetris group ($M = 14285.86$, $SD = 14043.20$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 2.43$, $p = 0.12$; effect of condition: $F(1,63) = 5.73$, $p = 0.02$). There was no difference in pre-training to post-training gains on Tetris efficiency (i.e., average number of unnecessary rotations and translations per piece) between the inactive control group ($M = -0.15$, $SD = 0.60$) and the combined Tetris group ($M = -0.42$, $SD = 0.91$) when controlling for pre-training performance (effect of covariate: $F(1,63) = 10.68$, $p = 0.002$; effect of condition: $F(2,63) = 0.80$, $p = 0.37$). These results indicate that the combined Tetris group improved their Tetris score significantly more than the inactive control group. There was no difference in gains between the group in Tetris efficiency.

Overall, across multiple cognitive measures, there is no evidence that *Tetris* playing resulted in improvements in cognitive skills as compared to a control group that did not play *Tetris*.

3.3 Discussion

Study 2 is a cognitive consequences study showing no benefit of playing *Tetris* on cognitive skills. The inactive control group took the same pre-training and post-training measures with the same elapsed time in between as the groups in Study 1. The participants in Study 2 did not complete any training in the weeks between these tests. This addition allows for comparisons to determine whether there was any effect of enhanced Tetris training or Tetris only training on gains in cognitive skills compared to gains from simply taking the tests a second time after a five-week delay. The results of this experiment revealed no benefit of the enhanced Tetris training or Tetris only training on gains in any of the spatial or cognitive skills measured when controlling for pre-training performance. The inactive control group actually outperformed the enhanced training group on two measures, indicating that training may have even suppressed gains on the card rotation and number comparison tasks. The only observed benefit of training was that participants in the Tetris only condition showed significantly greater gains in Tetris performance than participants in the inactive control condition.

This experiment reveals the cognitive consequences of enhanced Tetris training and Tetris only training. These results support a narrow view of transfer of procedural skill, as well as high domain specificity of Tetris expertise, as participants were not able to use any of the skills that may underlie Tetris performance outside of a game context. The current experiment therefore supports a *specific transfer* view of the scope of transfer (i.e., the practiced skills are only applicable in the situations they were practiced in), rather than a *specific transfer of general skills* view, as none of the skills that may be involved in *Tetris* play were improved outside of the game context. Participants who played the most *Tetris* (i.e., the Tetris only condition) improved more on their Tetris performance than the inactive control condition, revealing that the *Tetris* training was sufficient to improve performance on the trained task compared to simply retesting, but that improvement did not transfer to any other task. These results give additional evidence for the domain-specificity of *Tetris* expertise (Sims & Mayer, 2002).

4. General Discussion

4.1 Empirical Contributions

Concerning the value added question in Study 1, there was no observed benefit of the enhanced Tetris training on any of the 6 cognitive skills measured compared to a control condition that played Tetris only. Concerning the cognitive consequences question in Study 2, there was no evidence for cognitive benefits resulting from either type of Tetris training compared to an inactive control group. Judd (1908) advocated facilitating transfer by teaching skills in a generalizable way, and this experiment represents such an attempt. While Uttal et al. (2013) found a medium effect size on average for transfer of spatial skill training, the conditions that facilitate transfer were not well defined. This experiment used methods that successfully facilitate transfer in other domains of cognitive skill acquisition in an attempt at establishing a way to achieve transfer of spatial skills from playing a computer game. *Tetris* appears to be a particularly poor choice for improving cognitive skills, even though it is the most studied game in the literature on learning from games (Mayer, 2014).

4.2 Theoretical Implications

The results do not support the training hypothesis nor the theory of specific transfer of general skills from which it is derived. In short, learning of cognitive skills within *Tetris* appears to be very specific, such that skills do not transfer to contexts outside the game. This may be due to playing a fast-paced game that requires exercising the same skill within the same context throughout the game. These results add to the research base showing that playing computer games can foster in-game skills, reflected in improved game performance, that do not transfer to non-game contexts (Mayer, 2014).

4.3 Practical Implications

This set of studies provides no rationale for using *Tetris* as a vehicle for teaching transferable cognitive skills, even when supported with evidence-based adjunct activities. Although *Tetris* has been shown to a highly popular game, its value as a source of entertainment has not been shown to translate into value as an educational tool. Based on this study, coupled with the rest of literature, we are not able to recommend playing *Tetris* as a way to improve cognitive skills relevant for education. It should be noted that recommendations involving a spatial puzzle game may not apply to other game genres, such as first-person shooter games, role-playing games, or scenario-based games. Further, these recommendations do not apply to narrative games that teach science concepts: although narrative games can be weak learning tools compared to traditional instruction (Adams, Mayer, MacNamara, Koenig, & Wainess, 2011), previous research shows that learning outcomes from these games can be improved by adding reflective activities alongside game play (Pilegard & Mayer, 2016).

4.4 A Closer Look at Why Tetris Playing Did Not Train Spatial and Perceptual Skills

This work adds to the literature by showing that even when *Tetris* playing is ineffective as a vehicle for training cognitive skills even when supplemented with direct instruction aimed at getting students to think about the skills they are learning. Several factors could have contributed to the lack of a significant effects in this experiment. That is, it is possible that the lack of significant results in this study is due to the theoretical foundations (i.e., increasing one's declarative knowledge base about a skill may not necessarily increase the likelihood of transferring that skill), the manipulation (i.e., the lessons and worksheets failed to increase participants' declarative knowledge base), the dosage (i.e., the training was not long enough in duration to cause a significant change), the vehicle (i.e., *Tetris* may not utilize the targeted skills enough to produce an appreciable change in them), another limitation, or some combination. These possibilities are discussed below.

Further work is required to determine the validity of the theory that declarative knowledge about a spatial skill will increase the one's ability to use that skill in a novel situation. While this idea has been tested in the broader cognitive skills literature, it has not been similarly scrutinized in the domain of spatial skills. It remains possible that spatial skills are less affected by declarative knowledge than the other types of cognitive skills that have been tested in support of this framework. Future, more direct tests of this idea could mimic the methodology of experiments in the cognitive skills literature, such as prompting metacognitive or if-then verbalizations while completing a skill task (Berardi-Coletta et al., 1995). Further, it is possible that if the manipulation in this study had involved a non-Tetris context, then transfer may have been more likely. For example, Terlecki, Newcome, and Little (2008) found a significant benefit of Tetris playing on spatial task performance paired Tetris training with repeated spatial tests. It is possible that because the manipulation in the current experiment was entirely Tetris- based, participants were not able to effectively decontextualize any skills used in *Tetris*.

It is possible that the manipulation in this experiment did not have the intended cognitive effect—that is, it is possible that completing the lessons and worksheets in addition to Tetris training did not increase participants' declarative knowledge base about the target skills. Many previous experiments in this literature attempt to manipulate participants' development of declarative knowledge more directly, such as by requiring the participant to describe their thought processes out loud (Ahlum-Heath & Di Vesta, 1986; Berardi-Coletta et al., 1995), or by suppressing declarative knowledge formation in a dual-task paradigm (Sun, Merrill, & Peterson, 2001). The manipulation in the current experiment may not have achieved the same effect as these more direct manipulations. The effect of the current manipulation could be tested by surveying participants about their declarative knowledge surrounding the skills tested. Alternatively, the manipulation could be redesigned following principles for training transferable spatial skills as they emerge.

Another possible explanation for the current results is that the dosage in this current experiment (i.e., amount of training) was insufficient to detect any existent effect. Wright et al. (2008) assert that to train transferable spatial skills, "training should be intensive enough to produce large gains, to maximize potential transfer effects" (p.764). In their meta-analysis of spatial training studies, Uttal and colleagues (2013) agree that "demonstrating transfer often requires intensive training" (p.365), including a large number of trials or training over a large amount of time. However, specific definitions of *intensive enough* do not seem to exist in the literature, especially as simply giving participants a spatial task a second time can lead to large gains in performance (Uttal et al., 2013). Further, the relationship between amount of training and positive transfer effects is not always clear-cut. Indeed, some published studies show significant spatial transfer effects following an hour or less of training (e.g., de Lisi &

Cammarano, 1996; Wiedenbauer & Jansen-Osmann, 2008). It seems clear that both quantity and quality of training are important when transfer is the target outcome. This presents a logistic problem for researchers, as prolonged training studies are highly resource-intensive. Future work could use a greater amount of training or train subjects to asymptote in order to increase the possibility of transfer.

Finally, these results may demonstrate a more general failure of *Tetris* as a vehicle for training spatial skills. While the participants in this experiment were recruited on the bases of being non-gamers, pre-training Tetris ability was quite varied. It is possible that at low levels of game play, *Tetris* simply does not sufficiently tax any underlying spatial or cognitive skills to be a useful vehicle for training. As Tetris skill increases and participants reach higher, more difficult levels of the game, they may simultaneously gain strategies that allow them to obviate many mental operations including mental rotation and visualization (i.e., epistemic actions; Kirsh and Maglio, 1994). Therefore, despite decades of investigations making *Tetris* the most studied computer game, *Tetris* may simply be a weak tool for training spatial or cognitive skills, even when paired with evidence-based training enhancements.

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Table 1

Studies 1 and 2: Performance on Pre-training and Post-training Measure for Three Groups

Test (total possible)	Enhanced Tetris Condition		Tetris Only Condition		Inactive Control Condition	
	Pre	Post	Pre	Post	Pre	Post
Card rotation (80)	*M* = 45.2 *SD* = 16.5	*M* = 51.7 *SD* = 10.0	*M* = 42.2 *SD* = 17.8	*M* = 52.1 *SD* = 15.6	*M* = 53.3 *SD* = 18.5	*M* = 63.5 *SD* = 11.5
Tetris Mental rotation (RT, ms)	*M* = 2366.4 *SD* = 660.1	*M* = 1782.3 *SD* = 423.7	*M* = 2336.1 *SD* = 708.0	*M* = 1823.6 *SD* = 470.9	*M* = 1900.2 *SD* = 815.3	*M* = 1498.1 *SD* = 364.8
Paper form board (24)	*M* = 7.9 *SD* = 3.3	*M* = 9.4 *SD* = 5.3	*M* = 9.1 *SD* = 4.2	*M* = 9.2 *SD* = 4.8	*M* = 10.3 *SD* = 3.4	*M* = 10.4 *SD* = 4.6
Number comparison (48)	*M* = 19.2 *SD* = 5.3	*M* = 23.7 *SD* = 5.6	*M* = 21.8 *SD* = 6.8	*M* = 26.3 *SD* = 7.7	*M* = 20.6 *SD* = 6.7	*M* = 29.6 *SD* = 7.7
Useful field of view (128)	*M* = 69.3 *SD* = 16.5	*M* = 72.9 *SD* = 12.8	*M* = 72.1 *SD* = 10.3	*M* = 74.7 *SD* = 9.9	*M* = 76.5 *SD* = 12.7	*M* = 78.5 *SD* = 12.9
Corsi block-tapping (66)	*M* = 47.7 *SD* = 6.5	*M* = 47.8 *SD* = 5.9	*M* = 49.0 *SD* = 6.9	*M* = 52.7 *SD* = 6.6	*M* = 51.9 *SD* = 5.2	*M* = 51.2 *SD* = 5.6
Tetris High Score (n/a)	*M* = 5836.3 *SD* = 6715.8	*M* = 18027.8 *SD* = 8900.4	*M* = 5456.6 *SD* = 7406.1	*M* = 21753.1 *SD* = 20997.5	*M* = 9187.5 *SD* = 9732.3	*M* = 15127.9 *SD* = 20487.9

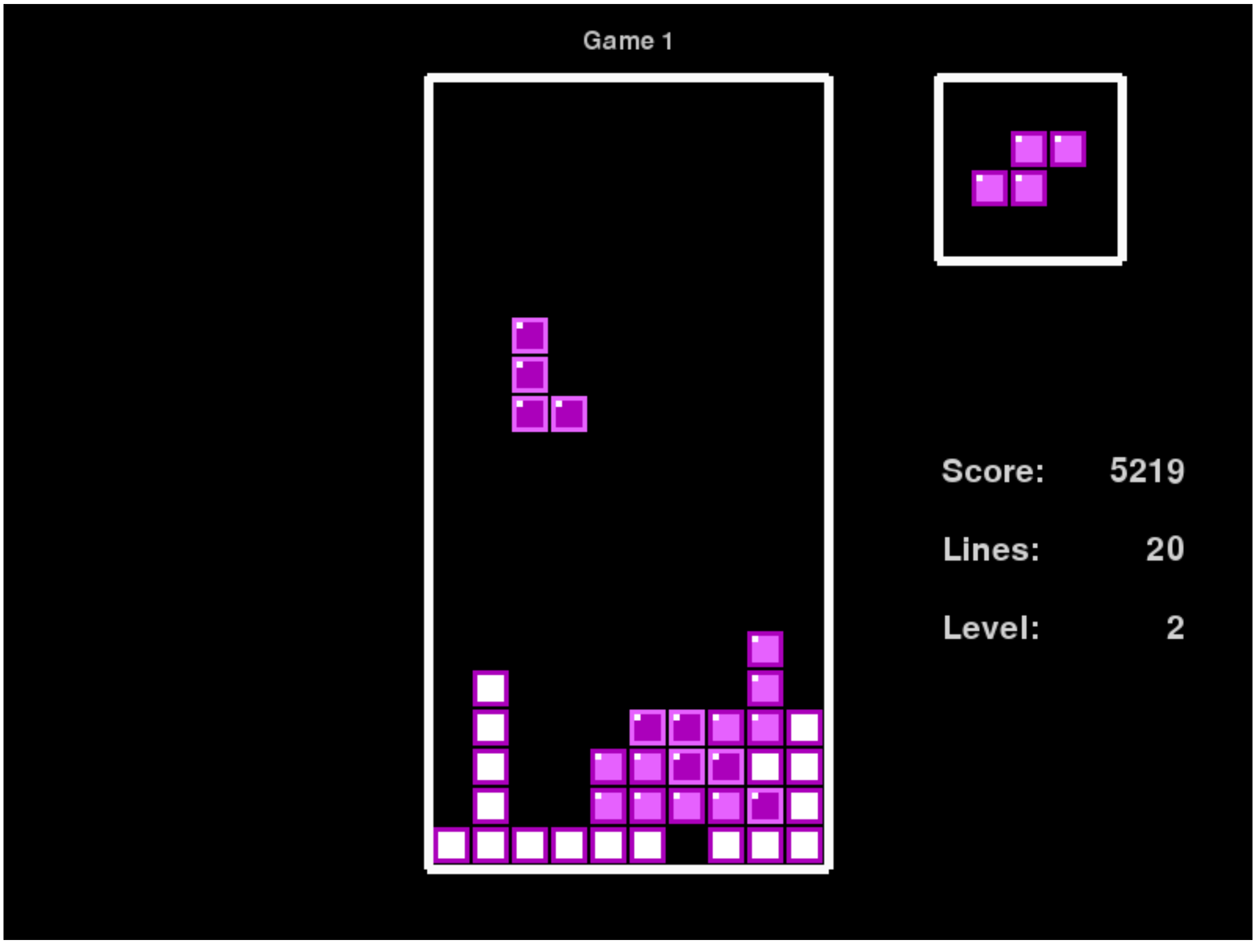


Figure 1. Screenshot from *Meta-T*.

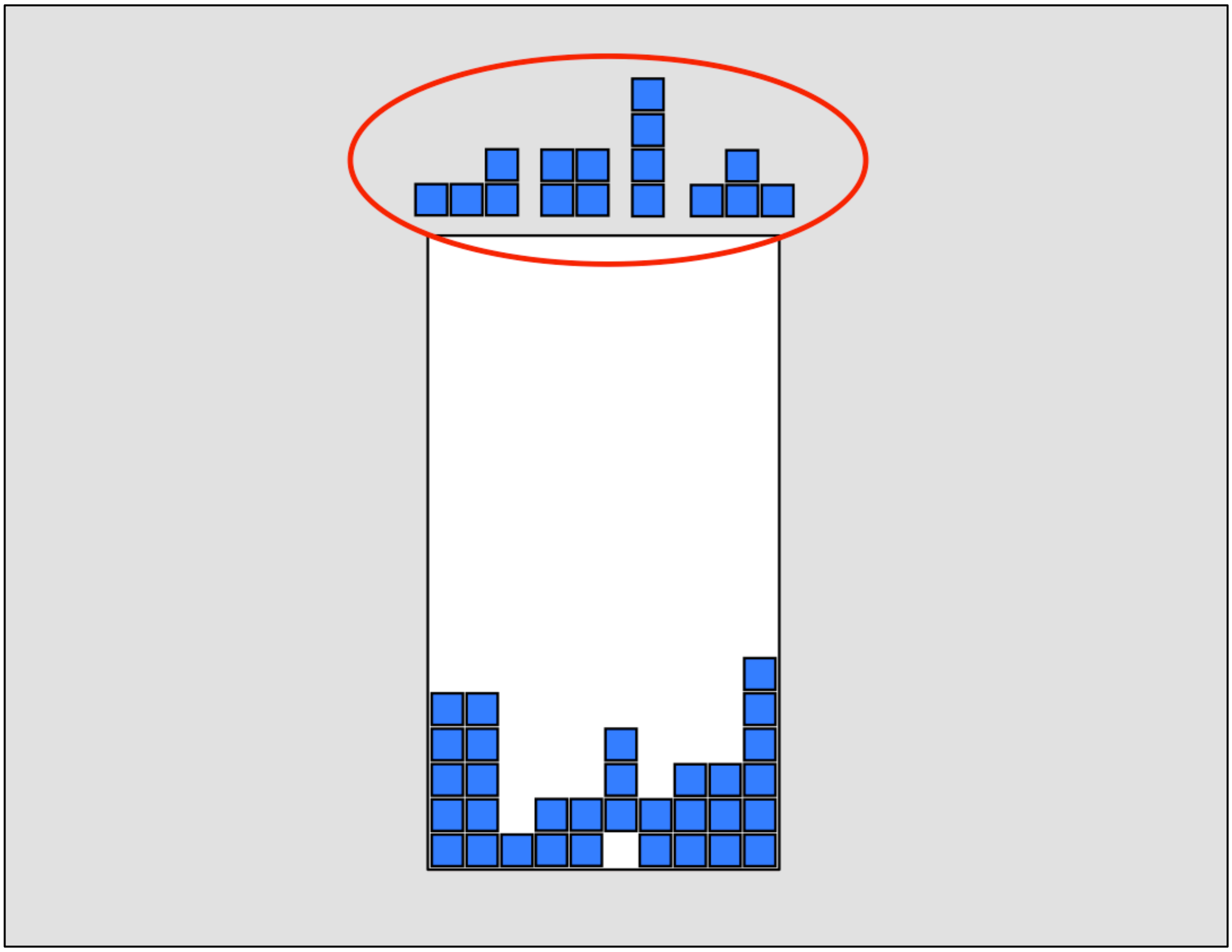
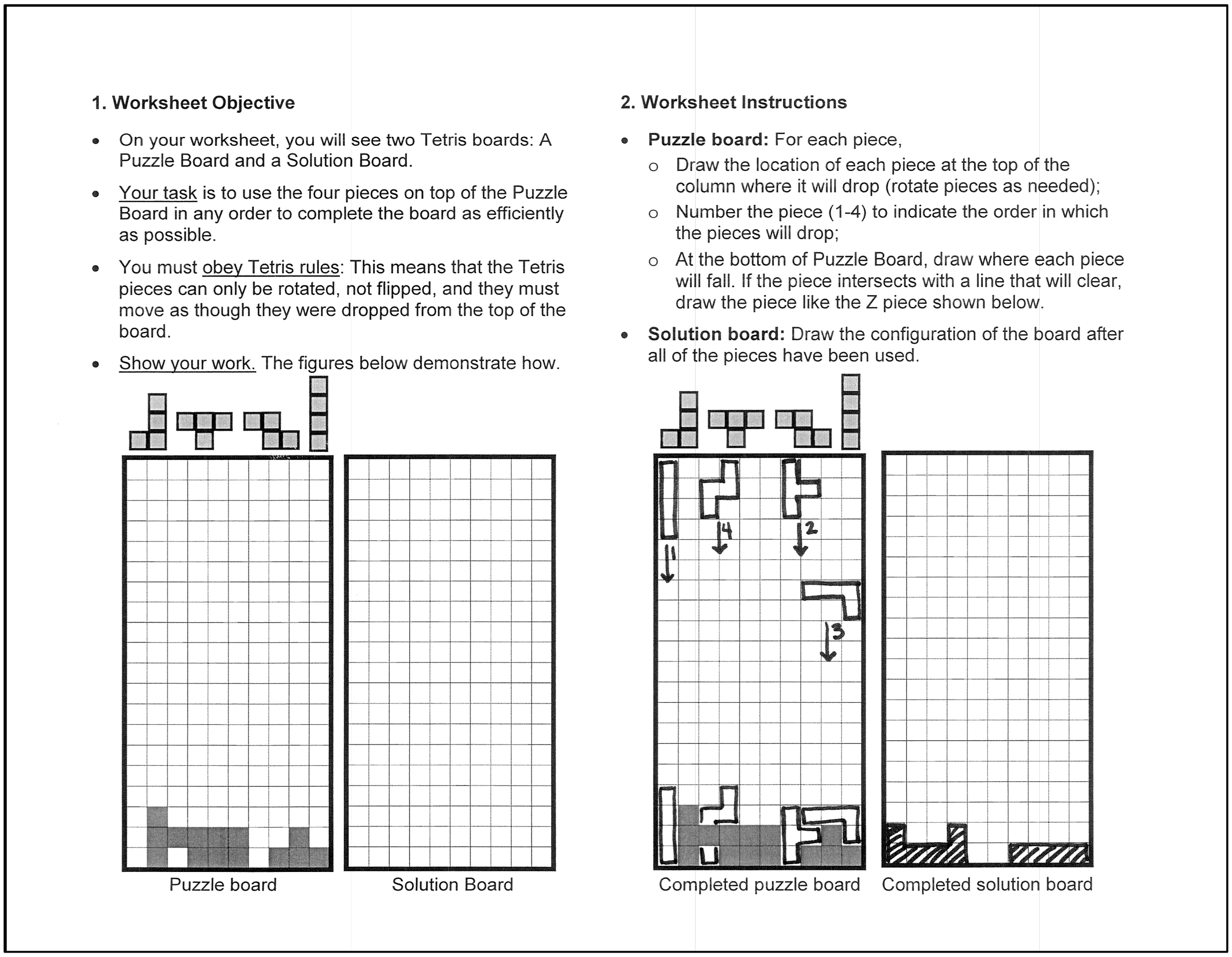


Figure 2. Screenshot from modeling slideshow.



1. Worksheet Objective

- On your worksheet, you will see two Tetris boards: A Puzzle Board and a Solution Board.
- Your task is to use the four pieces on top of the Puzzle Board in any order to complete the board as efficiently as possible.
- You must obey Tetris rules: This means that the Tetris pieces can only be rotated, not flipped, and they must move as though they were dropped from the top of the board.
- Show your work. The figures below demonstrate how.

2. Worksheet Instructions

- **Puzzle board:** For each piece,
  - Draw the location of each piece at the top of the column where it will drop (rotate pieces as needed);
  - Number the piece (1-4) to indicate the order in which the pieces will drop;
  - At the bottom of Puzzle Board, draw where each piece will fall. If the piece intersects with a line that will clear, draw the piece like the Z piece shown below.
- **Solution board:** Draw the configuration of the board after all of the pieces have been used.

Figure 3. Instruction sheet for worksheets.

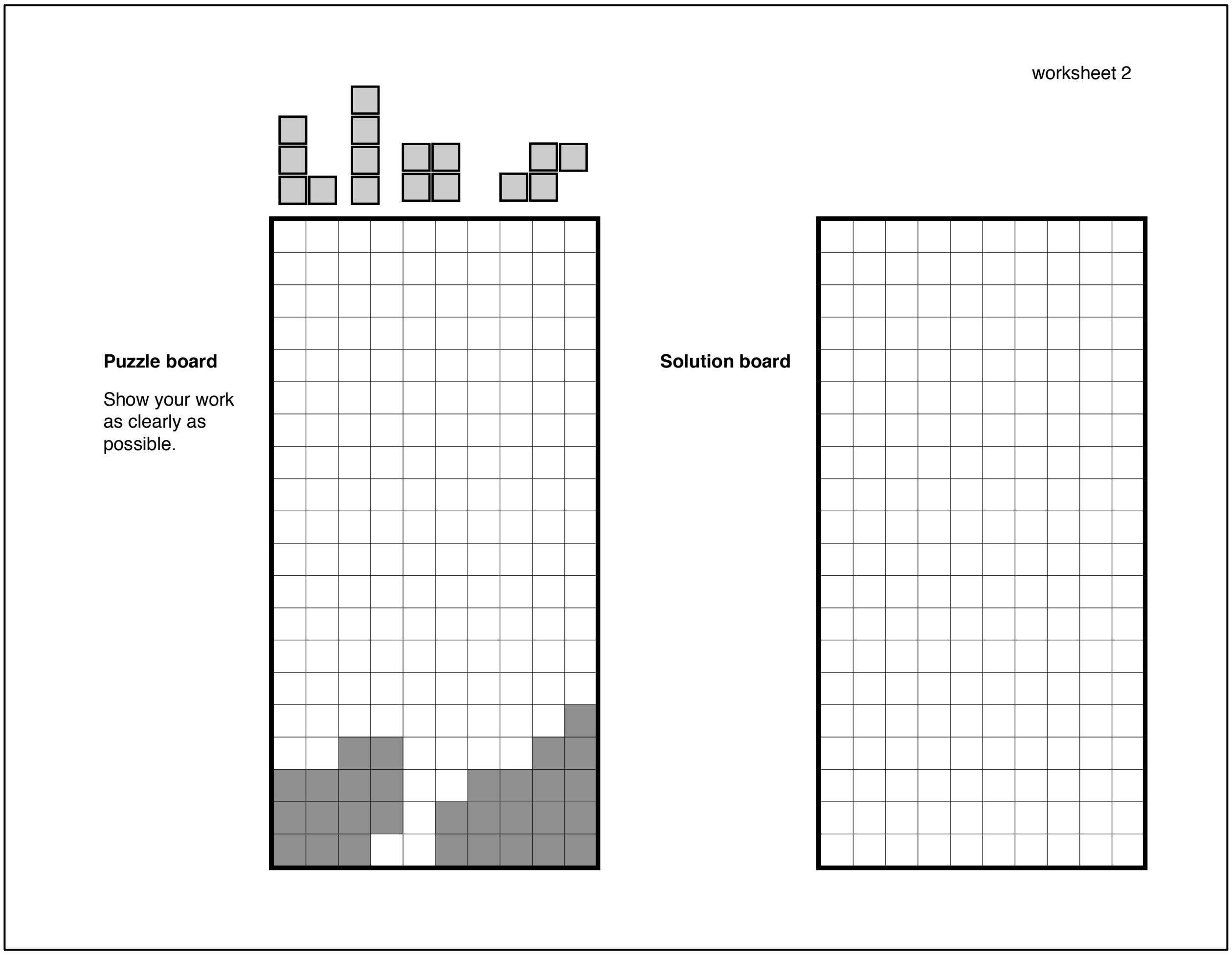


Figure 4. Example worksheet.