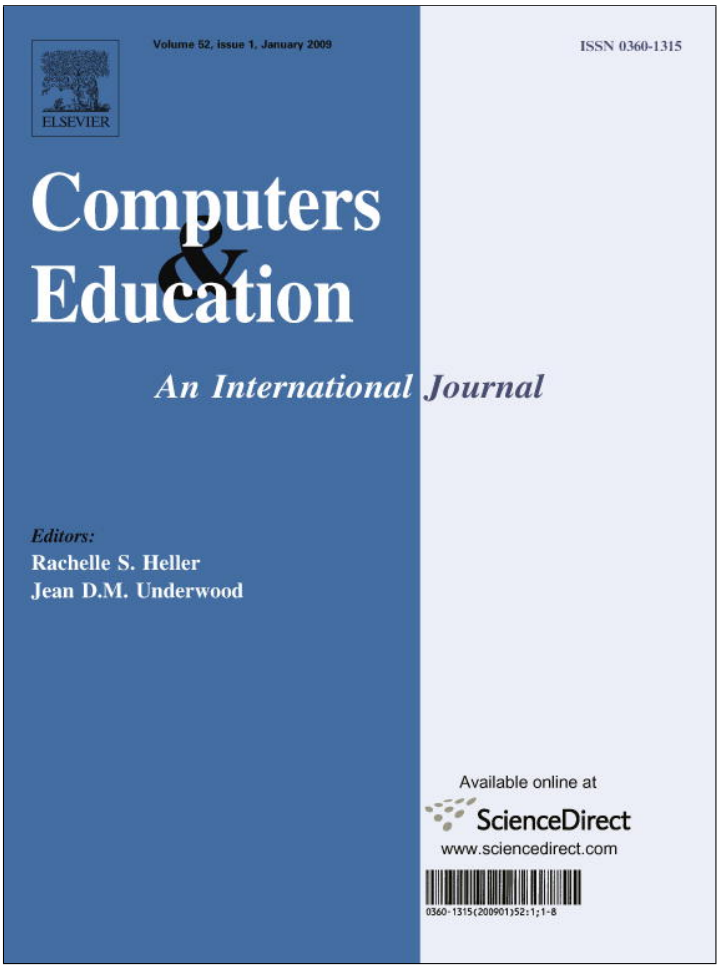

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Stills, not full motion, for interactive spatial training: American, Turkish and Taiwanese female pre-service teachers learn spatial visualization

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ABSTRACT

This study investigated how female elementary education pre-service teachers in the United States, Turkey and Taiwan learned spatial skills from structured activities involving discrete, as opposed to continuous, transformations in interactive computer programs, and how these activities transferred to non-related standardized tests of spatial visualization and mental rotation. The study used a pretest, intervention, posttest research design with experimental and comparison groups. The experimental group participated in transformational geometry visualization exercises, once a week for six weeks, for approximately 20 minutes each session. Instruments were standardized measures of spatial visualization and mental rotation; intervention activity worksheets directed the participants through 2D and 3D transformational geometry tasks in computer environments. For Turkish and Taiwanese participants, the experimental group improved significantly more than the control group in spatial visualization, while the American participants showed no such significant improvement.

1. Introduction

The current research investigated whether software with discrete, as opposed to continuous, transformations of shapes could be used to improve the spatial skills of female American, Turkish and Taiwanese pre-service elementary school teachers. A discrete approach to transformations of shapes allows users to interact with shapes at isolated regularly partitioned intervals along their trajectory of movement, e.g., still images. A continuous approach allows users to interact with the full trajectory of a shapes motion, e.g., full motion. The current study investigated if software featuring composition of discrete transformations (mental rotation, reflection, dilation, and translation) could improve pre-service teachers' mental rotation and spatial visualization skills. The investigators were also interested in how different countries and different cultures mediated such spatial skills training. Thus, the training took place in three different countries: the United States, Turkey and Taiwan. Moreover, since women have historically performed less well than men in spatial skills, this study focused specifically on improving women's spatial skills. Pre-service elementary school teachers, predominantly women, are powerfully positioned to influence the spatial learning of our children. The investigators chose to research a particular female population, female pre-service teachers. The conceptual elements of the current study were: a) improving spatial skills, b) using discrete transformations in software, c) comparing how country and culture mediate such spatial training, d) targeting women who have historically underperformed in spatial skills, and e) working with pre-service elementary school teachers, a group, predominantly women, positioned to teach our children spatial skills.

The authors investigated how pre-service elementary school teachers learned spatial skills, and to what extent the learning of these spatial skills transferred to standardized tests of spatial visualization and mental rotation. Toward that end, participants trained with a series of computer-based activities to practice spatial skills, and were evaluated through a simple pretest, intervention, posttest research design.

2. Literature search

Spatial visualization is an important predictive variable for women's mathematics achievement (Tartre & Fennema, 1995) and for a number of other fields, such as the hard sciences and engineering (Casey, Nuttall, Pezaris, & Benbow, 1995). Unfortunately, it is generally

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agreed that males outperform females in spatial tasks (Ferrini-Mundy, 1987; McGee, 1982; Hedges & Nowell, 1995), particularly on tasks involving three-dimensional objects (Geary & Gilger, 1992), mental rotation and spatial visualization (Voyer, Voyer, & Bryden, 1995). Spatial skills are important in mathematics and science, areas in which women have historically under-achieved (Casey et al., 1995). Therefore, there have been some concerted efforts to improve women's, as well as men's, spatial skills (Lizarraga & Ganuza, 2003; Okagaki & Frensch, 1994; Sims & Mayer, 2002; Terlecki, 2004).

One particular sub-population of women, pre-service elementary teachers, is uniquely positioned to break the cycle of females with underdeveloped spatial skills, yet they themselves are weak in the spatial skills we might like them to teach (Lord & Holland, 1997). Pre-service elementary teachers often demonstrate the same misconceptions observed in middle school students (Sunberg & Goodman, 2005; Lord & Holland, 1997). Manipulatives, and "virtual manipulatives" in computer programs, are plentiful in the elementary schools, but spatially unskilled elementary teachers overlook learning opportunities since they cannot teach what they themselves do not know (Franke, Carpenter, Fennema, Ansell, & Behrend, 1998).

2.1. Spatial reasoning in mathematics

Spatial reasoning plays a vital role in mathematical and scientific thought (Wheatley, 1998; Van Garderen & Montague, 2003). Spatial reasoning is used to represent and manipulate visual information during problem solving and in learning mathematical concepts, particularly those associated with measurement and geometry (National Council of Teachers of Mathematics, 2000). Visualization can be used as a tool for stimulating the teaching and learning processes of all areas of mathematics (Cruz, Febles & Díaz, 2000). Students' use of visual spatial imagery while solving math problems is positively and significantly correlated with mathematics problem-solving performance (Van Garderen & Montague, 2003).

The learning and transfer of spatial skills, such as spatial visualization (SV) and mental rotation (MR), although important to mathematics (Wheatley, 1998), remain resistant to the best efforts of educators and researchers to teach them (Terlecki, 2004). Through re-testing and practice, people can sometimes improve spatial skills within a narrow context, but such context-specific improvements have not transferred globally to other contexts (Olkun, 2003; Sims & Mayer, 2002).

People learn spatial skills through childhood recreational play experiences, through science/mathematics classes and through drawings, manipulatives and interactive software (Clements, 1998; Deno, 1995). Spatial visualization skills develop over a long period of time as people gain experience through real-world experiences (Robichaux & Guarino, 2000). Thus, it is probably most effective if spatial knowledge is presented in the classroom in connection with everyday experiences, and with virtual and real manipulatives related to concrete everyday objects. Further, it is important for students to become familiar enough with shapes through repeated problem solving that they can easily remember shapes to construct mental images of them (McLeay, 2006).

2.2. Spatial skills, psychological perspective

Mental rotation (MR), the ability to imagine shapes rotated into a new orientation (Shepard & Cooper, 1982), is an important spatial ability for at least two reasons: a) MR is a simple, relatively atomic sub-skill, used extensively in more complex spatial skills such as spatial visualization, and b) timed mental rotation is the spatial skill that shows the largest and most persistent gender differences, with females performing less well than males. Besides MR, another important spatial skill is spatial visualization (SV), "the ability to solve multi-step problems involving configurations of shapes" (Smith, 1998, page 21). SV is important because many academic spatial problems are multi-step and involve arrays of shapes. SV provides another accurate predictor of success in a variety of academic areas (Humphreys, Lubinski, & Yao, 1993).

In discussing training of spatial skills such as MR and SV, the constructs of near and far transfer are helpful. Near transfer means solving problems very similar to problems encountered in the learning phase; far transfer is solving problems new in both content and context (Mayer & Greeno, 1972; Barnett & Ceci, 2002). Studies involving training interventions in MR have occasionally resulted in near transfer, but very rarely in far transfer (Okagaki & Frensch, 1994; Terlecki, 2004). It is difficult to sort out why training sometimes does and sometimes does not result in significant improvements in MR.

A number of studies have also investigated if training could improve SV. In many of these studies, the training is so directly related to the pre and posttest (same content and same context) as to be an extreme form of near transfer (e.g. Embretson, 1987, 1992). Other studies have investigated whether SV training can result in far transfer. However, as with training for MR, significant results are mysteriously intermittent (Okagaki & Frensch, 1994; Sims & Mayer, 2002; Lizarraga & Ganuza, 2003). One problem may be that software designers do not attach importance to the severe limitations of the mental imagery necessary for spatial skills. It requires an effort of will for people to imagine shapes in their mind's eye (Hasher & Zacks, 1979) and even when they do so, they represent them as parsimoniously as possible, leaving out any details unnecessary for the functional task at hand (Kosslyn, 2005; Kosslyn, Ball, & Reiser, 1978). On the other hand, the dominant paradigm for visualization software is to combine hands-on interactive continuous dynamism for some spatial elements, with rigid constraints on other key spatial elements (Gerretson, 2004). For example in Geometers' Sketchpad (2008) and Cabri Geometrie (2008), one element is "nailed" down and the user is allowed to drag other elements in a full range of motion, while certain geometric properties are maintained, e.g., as the size and shape changes, but the figure remains a right triangle. The success of Geometers' Sketchpad (2008) and Cabri Geometrie (2008) for learning geometry (Han, 2008; Zimmerman & Cunningham, 1991) has spurred a profusion of related constraint/dynamic interactive geometry software. Although this combination of providing interactive continuous dynamism in some elements and constraining other elements is effective for students to learn geometric concepts and to interactively sort out the necessary and sufficient properties of geometric entities (Han, 2008), it probably exceeds people's limited capacity for mental imagery and is thus ineffective for learning spatial skills.

On the other hand a discrete, as opposed to a continuous approach, imposes less cognitive load on mental imagery in visualizing sequences of transformations. That the piece at the end of the chess move must land in the center of a square makes it easier to mentally visualize sequences of moves. Imagine a "continuous chess" without squares on the board where the pieces moved in the current manner except they could travel continuous distances, for example a rook move that traversed vertically a distance equivalent to 2.635 squares. In "continuous chess," it would be very difficult to visualize a sequence of three moves. Similarly, it is easier to visualize in Tetris, knowing

that pieces rotate in multiples of 90 degrees. Recreational activities may have evolved to stay within the limits of mental imagery. Software design may not always respect these limits.

Further, spatial visualization is defined as the ability to solve multi-step problems involving complex shapes, or configurations of shapes (Linn & Petersen, 1985; Smith, 1998; Zimowski & Wothke, 1986). It may be a failure of the mental imagery needed to visualize sequences of spatial transformations that limits people's spatial visualization skill. This study expanded on the theme of discrete states in spatial skills training by using multiple types of constrained discrete transformations (translations, rotations, reflections, dilations), as well as mental visualization of composition of discrete transformations. Another theme of the current study was to investigate the use of multiple contexts in spatial skills training. Over contextualized knowledge can interfere with transfer. As Bransford, Brown, and Cocking (2000) suggest: "If students learn only in [one] context, they often fail to transfer flexibly to new situations" (p. 62). Solving multiple cases may help students abtract the common principles.

In terms of ethnic, cultural and international differences in spatial abilities, the vast majority of studies focus on single testing events, not on repeated testing, nor on multiple testing with intervening training. A number of studies have compared gender differences in spatial abilities, typically finding that the male advantage is very robust across numerous countries and ethnic groups (Silverman, Choi, & Peters, 2007; Jahoda, 1980). Other studies have compared spatial abilities internationally and found no significant gender differences in spatial skills (e.g. Flaherty, 1997). What is missing from the research literature is a between country (or between ethnic group) comparison of attempts to improve spatial abilities.

There are many potential between-country cultural factors that might mediate spatial skills training, including: a) interactive visual electronic media such as computer games, b) availability of computers in homes and rates of computer literacy (Olkun, Altun, & Smith, 2005), c) popularity of recreational board games, d) spatial skills in the formal school curriculum, e) classroom culture, and g) type of writing system used, i.e., whether it is predominantly alphabetic, syllabaric, or ideogrammic. Ideogrammic writing symbols are often isomorphic with the concept represented: the symbol for water may look like waves. The classroom culture is quite different in different countries. For example, the USA university classroom culture is relatively more informal, with more equality between students and teacher, and more in-class discourse between students and teachers than in parts of Asia (Hatano & Inagaki, 1998; Redding, 1980) and possibly in other parts of the world such as Europe. These cultural differences that could confound spatial training effects are difficult to measure and account for. However, by conducting studies in multiple countries with a range of these cultural factors, perhaps the underlying patterns in the spatial learning may emerge from the fog of confounding cultural variables. Therefore, in the current study, we conducted the research in several countries with a range of relevant cultural differences.

3. Research questions

This study focused on the following research question: What is the viability of a spatial training, involving a) visualizing composition of discrete spatial transformations, and b) multiple contexts, in effecting transfer of spatial skills ability to spatial visualization and mental rotation tasks? To investigate this approach thoroughly, the spatial training was conducted a) across multiple sessions, and b) in several international cultural contexts. Thus, cultural context was a subsidiary variable, with multiple sessions as a minor component of the spatial training approach. The study also evaluated a second research question: How does cultural context mediate such spatial training?

4. Method

The research population consisted of undergraduate students majoring in elementary education and enrolled in a mathematics methods course required by their program. In all countries participating in the research, the institutions were large research universities located within an urban environment.

The study employed a pretest, intervention, posttest design, with experimental and comparison groups. Both groups were administered a pretest and posttest, composed of standardized tests of mental rotation and spatial visualization. During the interim between the pretest and posttest, the experimental group received six weekly 15 to 25 minutes long spatial training interventions involving composition of discrete spatial transformations in multiple contexts. The comparison group participated in typical coursework and class activities that were not spatial in nature.

In the next sections, we describe a series of two very similar experiments, which were conducted with equivalent populations in different countries. The first experiment was hosted in the United States and Turkey, employing a standardized test of spatial visualization for the pretest and posttest. The second experiment was hosted in the United States, Turkey and Taiwan, utilizing standardized tests of both mental rotation and spatial visualization for the pretest and posttest. Otherwise, the research methodology of experiment 1 was replicated in experiment 2. Thus, we begin with the description of the experiment 1 participants and instruments before introducing additional information related to experiment 2.

4.1. Experiment 1

Participants: Forty-eight students from a major university in Turkey, and 69 students from a major university in the southeastern United States participated in the study. All participants were female and enrolled in a similar two-course sequence of mathematics methods class in their respective countries. Three sections (consisting of two experimental and one comparison group) from the United States and two sections (one experimental and one comparison group) from Turkey participated in the study. All groups were intact sections of the course.

Table 1 displays participant information. The age of the participants ranged from 20 to approximately 40 years. What is striking is the similarity between the participants in the two countries. The only major differences are a) that the American students had taken a mathematics methods course, while the Turkish students had not, and b) consistent with the trend of life-long learning in the United States, the age range of the American students was greater than that of the Turkish.

Table 1
Participant information

1st Experiment	Age range	Year at University	Future	Prior Math.Methods	Major-experimental group	Major-control group	Familiarity with instrument
1st Experiment							
TR	18–22	3	Classroom teacher	None	Elementary education	Elementary education	None
USA	19–35	3	Classroom teacher	Math. Methods I	Elementary education	Elementary education	None
2nd Experiment							
TAI	21–23	3	Classroom teacher	Math. Methods I	Special education	Elementary education	None
TR	18–23	3	Classroom teacher	Math. Methods I	Elementary education	Elementary education	None
USA	19–34	3 & 4	Classroom teacher	Math. Methods I	Elementary education	Elementary education	None

Instruments: Pretest and posttest used a standardized timed test of spatial visualization, the Differential Aptitude Test (DAT), Space Relations Subset (Bennett, Seashore & Wesman, 1947). The DAT is a 60 items multiple-choice "surface development" test, in which participants pick a perspective drawing of a three-dimensional shape that could result from folding up a flattened pattern; participants complete as many items as they can in 25 minutes. The DAT was used because it did not structurally relate to the experimental intervention activities, thus it was a reasonable measure of transfer of spatial visualization skills. One week before and then one week after the experimental interventions, participants (in both groups) took pretests and posttests with the exact same versions of the DAT.

4.2. Experiment 1 and experiment 2

Experiment 2 was a replication and refinement of experiment one. As such, experiment 2 was identical to experiment one, with two notable differences. The first change was the addition of a standardized test of mental rotation, the Flags test of mental rotation (Thurstone & Jeffrey, 1959), to the pre and posttests. The second change in experiment 2 was the inclusion of an additional country, Taiwan, in the study. Taiwan was chosen because, as an Asian country, it has distinctly different cultural attitudes towards classroom culture and mathematics than the USA or Turkey. The addition of an Asian country provided a broader cultural diversity in order to observe how classroom culture interacted with spatial training. Furthermore, Taiwan, with Mandarin Chinese as its language, employs an ideogrammic writing system; the investigators thought that the use of ideogrammic writing systems might have some effects on visuospatial literacy.

4.3. Experiment 2

Participants: The research study included 29 Turkish, 44 Taiwanese and 97 southeastern USA female students enrolled in major universities in their respective countries. All participants were enrolled in the mathematics methods course that addressed aspects of school geometry, and were grouped within intact classes as either experimental or comparison sections. In the United States, there were two classes of comparison sections and two experimental sections. In Turkey, and also in Taiwan, there was one comparison section and one experimental section. Table 1 shows more demographic information about the participants. As in experiment 1, there are more similarities than differences between counties. However, there are two notable differences: a) in contrast with the Turkish and Taiwanese students in the junior year, the American students are in junior and senior years, and b) the age range is greater for the American students.

Instruments: In addition to the DAT, the Flags test of mental rotation (Thurstone & Jeffrey, 1959) was administered as pre and posttests. The Flags test consists of 126 items, as many as possible to be completed in five minutes. The Flags mental rotation test was added because: a) mental rotation is one of the most fundamental of spatial abilities, and b) mental rotation is a subset skill for spatial visualization. The investigators thought the addition of a standardized mental rotation test might provide a broader assessment of the spatial skills training.

Materials: Participants in the experimental group, during six weekly 15 to 25 minutes interventions, worked through activities with diagnostic work sheets involving three pieces of software, which are described below. The activities contained a variety of exercises such as: a) drawing how they thought a transformed object would look, b) responding to essay questions that were aimed at evaluating their conceptual understanding (e.g., Does the order of transformations matter?), and c) playing games involving visualizing sequences of transformations of two-dimensional geometric shapes on an x-y Cartesian coordinate system.

During the experimental intervention, experimental groups used three types of software. The Mathemagic™ computer program, developed and used by Malone, Boase-Jelinek, Lamb, & Leong (2004) in their studies of spatial "misperceivers," served as one of the experimental environments. This computer program is well-suited for learning to visualize sequences (composition) of discrete transformations in a two-dimensional plane because rotations, for example, are in discrete multiples of 90 degrees. The second piece of software used in the experimental intervention was a computer program applet (Keller, Wasburn-Moses, & Hart, 2002). Participants used these applets to build objects out of cubes and explored two-dimensional views of these three-dimensional objects, including front-right-top views, isometric views, mat plans, and rotations through different axes. These tasks were designed to enhance learners' pedagogical content knowledge in spatial visualization skills, and teaching and learning issues related to isometric drawings. The third piece of software used in the experimental intervention was CopyCat (Morey, 2008), a geometry game where players manipulate a patterned cube, and use the cube as a stamp to reproduce a tiled pattern.

Here are three key points about the software used in the experimental intervention: a) all three pieces of software used discrete, as opposed to continuous transformations, b) the software was used in the context of activity worksheets (translated for each country), so that exposure to the software was fairly standardized across country, and c) the same three pieces of software and the same activity worksheets were used for the experimental interventions in all three countries and in both experiments 1 and 2.

5. Results

Findings are given separately for experiment 1 and experiment 2, due to the change in instrumentation and population.

5.1. Experiment 1

The Turkish participants, experimental and control groups lumped together, improved significantly from pretest (M = 29.92, SD = 6.63) to posttest (M = 36.8, SD = 8.17), ($t[47] = -10.1$, $p = 0.001$) as shown in Table 2. The effect size of 1.45 was large. However, the experimental group improved significantly more than the control group. An analysis based on gain scores revealed a significant difference between the experimental and control groups in favor of the experimental group, $F(1, 47) = 6.54$, $p < 0.01$. The between groups effect size of 0.72 was medium. This finding indicates the intervention significantly improved the spatial visualization scores of the Turkish participants.

Table 2 also shows that for the American participants, neither comparison nor experimental groups made improvement from pre to posttest. Although the experimental group gained more than the comparison group, this difference was not statistically significant, $F(1, 67) = 1.06$, $p < 0.307$. This finding shows that neither retaking the test nor the intervention had an effect on spatial visualization scores of the American participants. Furthermore, Table 2 depicts the pre and posttest scores of American and Turkish participants, experimental and comparison groups combined. As can be seen in Table 2, although the Turkish participants scored less than the American participants on the pretest, they achieved the same score on the posttest.

To analyze the research question "How does cultural context mediate such spatial training?" required a slightly more complex analysis. Comparing just the DAT pretests (or just posttests) across country would not reflect how training differentially affected populations in the different countries. Therefore the investigators used a two-way mixed (between–within) repeated measures ANOVA, using both DAT pretest and posttest as the within subjects factor, and which country and experimental condition (control versus experimental) as between subjects factors. This repeated measures ANOVA revealed that the interaction between DAT (pretest and posttest) and country was highly significant, $F(1, 113) = 15.9$, $p < 0.0001$. The interaction between DAT and condition (experimental versus control) was close to significant, $F(1, 113) = 3.55$, $p < 0.062$.

5.2. Experiment 2

Table 3 depicts the pre and posttest scores and standard deviations on DAT for all three countries. As in the first experiment, the Turkish participants made lower scores than the American participants on the pretest, but they recovered this difference and achieved almost the same score with the American participants on the posttest of DAT. The Taiwanese participants started out and stayed ahead of the other two countries.

As with the first experiment, for the second experiment, the investigators wanted to analyze the question, "How does cultural context mediate such spatial training?" Thus, the investigators also ran a two-way mixed (between–within) repeated measures ANOVA, using DAT pretest and posttest as the within subjects factor, and which country and experimental condition (control versus experimental) as between subjects factors. The interaction between DAT and country was significant, $F(2, 138) = 3.85$, $p < 0.024$. The interaction between the DAT and experimental condition (control versus experimental) was also significant, $F(2, 138) = 5.03$, $p < 0.026$. The differences between the countries on the DAT were also significant, $F(2, 138) = 5.9$, $p < 0.003$.

When running the same type of analysis and selecting only the experimental groups, the between country differences on the DAT were significant, $F(2, 75) = 8.35$, $p < 0.001$. However, when selecting control groups only, the between country effects were not significant, $F(2, 60) = 0.523$, $p < 0.595$). This last result indicates that between-country, cultural effects played a large and significant role in the effectiveness of the training, as measured by improvement on the DAT test of spatial visualization.

For the Flags test of mental rotation, the investigators ran the same type of two-way mixed (between–within) repeated measures ANOVA, only using the Flags test as the pretest/posttest for the within subjects factor. The interaction between the Flags test and country was significant, $F(2, 129) = 7.062$, $p < 0.001$. The interaction between the Flags test and experimental condition was not significant, $F(2, 129) = 1.623$, $p < 0.205$. The between country difference was also significant, $F(2, 129) = 4.84$, $p < 0.009$. These results suggested significant differences between countries on the Flags test of mental rotation. When running the same type of repeated measures ANOVA, but selecting only participants in the experimental condition, between country differences on the Flags were significant, $F(2, 80) = 3.075$, $p < 0.052$.

Table 2
Pretest, posttest, and gain score of Turkish and USA participants on DAT

Country	Group	N	Pretest mean	SD	Posttest mean	SD	Gain score	SD
Turkey	Experimental	18	29.3	6.95	38.3	8.96	9	4.71
	Control	30	30.3	6.53	35.9	7.67	5.6	4.30
USA	Experimental	38	35.9	6.99	37.8	9.25	1.87	8.28
	Control	31	35.48	8.42	34.9	13.1	−0.58	11.5

Table 3
Pre and Posttest means of participants from the 3 countries on DAT

Country	N	DAT pretest	SD	N	DAT posttest	SD
USA	97	33.30	10.72	76	34.68	11.35
Turkey	24	30.25	8.76	24	34.0	8.9
Taiwan	44	37.95	8.14	44	41.5	9.28

When selecting only participants in the control condition, the between country differences were not significant, $F(2, 49) = 2.53$, $p < 0.09$. This is an intriguing result. Within each of the countries, there were no significant differences between experimental and control conditions (training versus no training). Yet, differences between countries (as measured by the Flags test of mental rotation) were amplified by training.

As a new testing instrument in the second experiment, we used the Flags test of mental rotation, as shown in Table 4. On the Flags, all groups improved from pretest to posttest, however there were no significant differences between control and experimental groups on gains from pretest to posttest. Thus, the training was ineffective for mental rotation, by this measurement. The Turkish scored highest on the pretest of mental rotation, followed by the Taiwanese, and then the American participants. However, in terms of gains, the order was reversed, with the countries starting behind making the most progress. The American participants progressed farthest, followed by the Taiwanese, then the Turkish.

Tables 5 summarize the major results of the experiment 2, showing the significant differences from pretest to posttest. In these tables, participants from the USA, Turkey and Taiwan are treated as separate populations. The upper portion of Table 5 shows the results for the Flags test of Mental Rotation and lower part of Table 5 shows results of the Differential Aptitude Test, Space Relations Subset (DAT) test of spatial visualization.

For the within subjects comparison of pretest to posttest scores (both control and experimental groups), paired samples *t*-tests were used. For the between group comparison (control versus experimental group) of the pretest to posttest improvement (posttest minus pretest), one-way between-groups (independent groups) ANOVA tests were used. The "bottom line" on the results is as follows: All participants improved on MR from pre to posttest, but the intervention did not make a difference for MR. For MR, the repeat of the test resulted in a significant improvement, however the training did not make a difference in MR.

On the DAT test of spatial visualization, the intervention did not make a difference for the American participants (Table 6). However, for both the Turkish and Taiwanese participants, the training made a significant positive difference for SV. For the Turkish, $F(1, 23) = 4.34$, $p < 0.05$. The effect size was 0.8. For the Taiwanese, $F(1, 43) = 7.39$, $p < 0.01$. The effect size was 0.77. For the Turkish and Taiwanese participants, the group receiving the training improved significantly more than did the control group.

Table 4
Pre and Posttest means of participants from the 3 countries on the flags test

Country	N	Flags pretest	SD	N	Flags posttest	SD
USA	70	59.32	22.96	70	80.61	27.51
Turkey	28	82.21	26.65	26	89.58	25.40
Taiwan	44	62.34	21.82	44	76.34	24.23

Table 5
Flags mental rotation and DAT spatial visualization test-pre to post significant differences

Test	Country	Within subjects (all participants)	Between groups (experimental versus control)
Flags MR	USA	SIG, 0.0001, $t = 6.33$	Not significant
	Turkey	SIG, 0.02, $t = 2.47$	Not significant
	Taiwan	SIG, 0.0001, $t = 7.89$	Not significant
DAT	USA	Not significant	Not significant
	Turkey	SIG, 0.001, $t = 3.7$	SIG, 0.05, $F = 4.34$
	Taiwan	SIG, 0.001, $t = 4.80$	SIG, 0.01, $F = 7.39$

Table 6
Pretest, posttest, and gain score of participants on DAT-spatial visualization

Country	Group	N	Pretest mean	SD	Posttest mean	SD	Gain score	*F*	*p*
USA	Experimental	40	32.83	12.93	33.3	12.48	0.47	0.76	0.385
	Control	32	35.5	8.77	35.44	9.94	−0.06		
Turkey	Experimental	14	28.86	8.06	34.44	9.33	5.58	4.34	0.05
	Control	10	32.2	9.76	34.36	8.75	2.16		
Taiwan	Experimental	24	39.75	7.72	45.00	7.3	5.25	7.39	0.01
	Control	20	35.8	8.3	37.3	9.82	1.5		

Table 7
Pretest, posttest, and gain scores on the flags test of mental rotation

Country	Group	N	Pretest mean	SD	Posttest mean	SD	Gain score	*F*	*p*
USA	Experimental	45	52.42	23.66	70.44	30.31	18.02	1.575	0.214
	Control	23	48.17	28.15	74.91	32.36	26.74		
Turkey	Experimental	15	86.07	26.174	89.33	24.6	3.26	2.19	0.087
	Control	10	76.20	27.79	87.00	27.34	10.8		
Taiwan	Experimental	24	66.29	20.9	80.8	27.3	14.51	0.016	0.899
	Control	20	57.6	22.5	71.85	22.36	14.25d		

Table 6 shows the breakdowns of between group comparisons for the DAT by country in more detail. Similarly, Table 7 shows group comparisons in each country for the Flags test of mental rotation. Note that there were no between group differences on the Flags test of mental rotation.

6. Discussion

The major research question asked: "What is the viability of a spatial training involving: a) visualizing composition of discrete spatial transformations, and b) multiple contexts – to effect transfer to spatial visualization and mental rotation tasks?" The most important results were the significant between-group differences (experimental versus control) found for spatial visualization, but not for mental rotation. The spatial training with sequences of discrete transformations worked for spatial visualization, but not for mental rotation. This is consistent with theory, since the training involved sequences (composition) of spatial transformations, and spatial visualization, by definition, involves "the ability to solve multi-step problems involving configurations of shapes" (Smith, 1998; Zimowski & Wothke, 1986; Linn & Petersen, 1985). Training with visualizing sequences of transformations is a good training for multi-step problems involving complex shapes. The correspondence is obvious. The authors also believe that the success of the training using discrete transformations – stills not full motion – is the result of less cognitive load in forming the necessary mental imagery for spatial visualization.

Moreover, the improvements in spatial visualization measured by standardized test are close to far transfer. While the classroom context was the same for both training and pre and posttest, the content of the training was structurally different from the pre and posttest of spatial visualization used in the study. The DAT, space relation subset, involves surface development, e.g., determining which of several shapes, represented by perspective drawings, could result from folding up a flattened pattern. None of the experimental training involved anything remotely resembling surface development. The shapes were not similar between the training and pretest/posttest situations. Thus, in Turkey and Taiwan, the spatial visualization training resulted in significant improvement of spatial visualization, something close to far transfer of spatial visualization skills. Training with visualizing sequences of discrete transformations of shapes, seems viable as a training tool for other spatial visualization tasks.

Although the training involved numerous opportunities to practice mental rotation, the groups experiencing the spatial training improved no more than those who did not. This, also, is consistent with theory. Historically, training for mental rotation has produced mixed results, with positive results occurring with a close structural and content (same shapes) correspondence between the training and the testing situations (Sims & Mayer, 2002; Terlecki, 2004). In the current study, by design, there was no direct structural or content correspondence between the training and testing situations. Secondly, some of the problems in the training involving sequences of spatial transformations were amenable to the use of deductive or key-feature strategies, as opposed to strategies involving mental rotation.

In terms of software design, the results suggest that training composition (or sequences) of discrete spatial transformations is viable for spatial visualization training. A logical next step in research would be to compare the effects of training for spatial visualization between compositions of discrete spatial transformations versus continuous transformations, such as seen in the interactive (constraint–dynamic) dynamic geometry software.

The current study also asked how cultural context mediates spatial training involving sequences of discrete spatial transformations. The training resulted in significant improvements in spatial visualization in Turkey and Taiwan, but not in the United States. In the cross-country analyses for both experiments, the interaction between DAT and country was significant, indicating that between country differences strongly mediate effectiveness of spatial visualization training. In experiment two, with tests of mental rotation included in the design, the interaction between country and performance on the mental rotation tests was also significant. Perhaps most telling, international differences in progress on mental rotation and spatial visualization were significant for experimental groups (those receiving spatial training), but not for control groups (no training). These results suggest that cultural differences strongly mediate effectiveness of spatial skills training. It is well known that the classroom climate for university education in the United States is much less formal than in many other countries such as Taiwan and Turkey. As a result of informality, as well as stronger human subject research regulations, the American participants may not have taken the experiment training as seriously as the participants in Turkey and Taiwan. Moreover, American university research regulations concerning human subjects require that students be informed that participation in research, even if for extra credit, is optional. This was not a requirement in the other two countries. In fact, research compliance is a moot point in some cultures where the respect given to the educational enterprise assumes that students' responsibilities include participation in research endeavors. Another difference between the American situation and that of Taiwan and Turkey was that the American courses, both experimental and comparison sections, involved the use of hands-on exercises with manipulatives and progressions from concrete to abstract. Perhaps this overshadowed the experimental intervention.

However, one must look for reasons why the United States was the only country without significant increases in spatial visualization in the intervention groups. The most obvious explanation may be the informality of classroom culture and the research regulations concerning human subjects in the United States.

6.1. Educational implications

The results have three important implications for education. First, the findings of this study tentatively show that spatial visualization can be improved at a far transfer level through training if it involves relevant and motivating tasks. Second, a program involving multiple contexts and multiple pieces of software may be more likely to increase spatial visualization skills. Third, the results suggest that activities based on composition of discrete, geometric transformations may affect far transfer and some generalization of spatial skills; i.e., the interventions were not specifically related to the DAT spatial visualization test used for the pre and posttests.

As discussed earlier, discrete (as opposed to continuous transformations) provide a computation advantage that may make it much easier to mentally visualize sequences (composition) of different types of transformations (rotation, scaling/dilation, translation). Given the results of the current study, this computational advantage of discrete transformations probably eases spatial learning, especially for

students with weaker spatial skills. The current authors recommend discrete spatial transformations in software for training spatial visualization, especially for women in applied and social fields where students may not be self-selected for an affinity to spatial tasks.

7. Conclusion

In two out of three countries, compared with participants in comparison groups, participants receiving spatial visualization training involving composition of discrete geometric transformations improved significantly more in spatial visualization skills. Moreover, the training had very little structural similarity to the pre and posttest of spatial visualization. This suggests the viability of visualizing compositions (or sequences) of discrete (as opposed to continuous) spatial transformations as a training technique for far transfer to spatial visualization. Moreover, the spatial training was much more successful in Taiwan and Turkey, cultures with a relatively more formal classroom culture, than in the United States where there is relatively more informal classroom culture and more equality between instructors and students. This suggests that introducing new teaching techniques, under the guise of research, is likely to be more successful in countries with more formal classroom cultures.

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