When students imagine numbers in color:
Is there a relationship between creativity and mathmatic ability?

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Introduction

The manner in which individuals envision number for arithmetic processing is a fascinating topic subject to much debate among neuropsychologists. Numerous theories have been asserted on the myriad possible mechanisms of cognitive numerical processing. As a result, much debate has been generated about the essence of mathematical thinking. On one hand, proponents of a semantic theory of number sense focus on word representations, while another group has concentrated research on how subjects achieve direct abstractions, or symbolic representational forms of numbers.

Still other scholars posit that imagining digits in color may be an intermediate step in numeric processing for some individuals (Seron et al., 1992.) Imagined colored number representation are estimated to occur in approximately ten percent of the population (Galton, 1883 and Seron, et al. 1992). This trait, or ability, appears similar to synesthesia which has been discussed at length by Marks (1978). Synesthesia is a psychological phenomena where two senses share information.. When students envision numbers during mental calculations, their ability to vividly imagine digits in color could affect number retrieval ability by serving as a memory stimulus. Conversely, imaginative number representations could simply be an expression of creativity. The present study addresses issues of whether children develop vivid number color imagery as a cognitive strategy to aid mathematical reasoning, or as a function of creative thinking. By way of introducing the topic, a brief look at the theory of mathematical thinking is offered.

The Language Number Connection

Scholars of semantic mathematic cognition like to envision mathematical reasoning as a declarative process governed by word symbols (Gelman and Gallistel, 1987). Other contemporary theorists, however, tend to advance the concept that mathematical reasoning occurs in multiple forms including verbal, abstract and numeral codes (Noel and Seron, 1997; Dehaene, 1997; McClosky et al., 1987). For an introduction to various prevailing theories of number sense, see Volume 44 of *Cognition* (1992). To most observers, mathematical reasoning seems to rely on a transcoding process that involves rearranging words or symbols according to a set of sequential steps dependent on numerous symbolic formats. Number sense includes subitization of sets (Dehaene, 1997) and counting (Gelman and Gallistel, 1987). Higher mathematical processing encompasses encoding (Campbell & Clark, 1987), abstract representation (Noel and Seron, 1997) and accessing memorized tables of calculation (McClosky, Sokol and Goodman, 1987). The prevailing theories and issues about mathematic cognition tend to revolve around how and where representations of number occur in the mind and brain.

According to Gallistel and Gelman (1987), mathematical thinking is generated to some degree in the language centers of the brain by way of verbal counting. In their research they observed and interviewed preschoolers and their parents to determine the way children's language of number develops. According to the researchers, a child's understanding of number must include:

1. A one to one correspondence for items in an array.
2. A stable order of numerons in a sequence
3. A representation of the last item as the whole amount of the set.
4. An abstraction to a variety of collections.
5. An understanding that order is irrelevant to amount.

Each criterion relies on the notion that counting is essential to mathematical function. However, according to Dehane (1997) counting is both a semantic and symbolic process which may begin with subitization during infancy (Dehane, 1997).

The Number Symbol Connection

Subitization involves innate apprehension of amount based on an intuitive ability to the number of objects in a small set. For instance, both crows and rats have demonstrated an ability to discern amount when they are presented with collections of food bits. Certain monkeys are able to associate number symbols with amounts of food. Appreciation of amount seems to be ingrained in the basic structures of human and animal brains. Associating number symbols with amount occurs in bird, mammal and infant brains. Dehaene (1997) describes the subitization ability found in animals, infants and young children as an automatic recognition of amount that may precede semantic counting ability by years, perhaps as early as infancy.

A number of theorists (Gelman and Gallistel, 1987; Ashcraft, 1992; Dehane, 1992) conclude that within various task requirements, mathematic cognition includes apprehension of amount, recognition and production of verbal and visual symbolic representation, and accessing tables from memory. Serone et al., Ashcraft and Dehaene, reviewing and presenting prevailing theory in Volume 44 of *Cognition,* recognize that some sort of transfer between number shape and number name occurs during calculation. Both Ashcraft (1992) and Nöel & Seron (1997), however, believe that some numeric processing disregards language and relies on numerical representations as well as memorized arithmetic facts.

The McClosky, et al. (1987) perspective of number processing involves a multifaceted system of representations. Production and comprehension rely on external systems, while a more central system is essential to semantic representation. In this model, all numeric processing; i.e. calculation, magnitude comparison, and parity judgment, occurs in an abstract representational form. Campbell and Clark's (1988) interactive model presents a three-way exchange of abstract calculation procedures which can occur both in Arabic and verbal representations. They suggest that all codes or forms of number representations are task specific and can be equally accessed.

Noel and Serone (1997) and have concentrated their work on how the mind processes numeric symbols. They argue that intermediate representations of number involved in encoding depend on the actual lexico-syntactic structure of numbers. In their research, numeric processing with Roman numerals was compared to processing of number words. It was assumed that the time it took to quantify Roman numerals would be longer, since intermediate representations of the actual numbers involved a two step addition or subtraction process. In a typical human scenario, The Roman numeral VI translates first to *five plus one* before it codes to the number *6*. The ease with which research subjects were able to transcode the two types of numbers (Roman numerals or number words) into symbols depended on the speed of their internal methods.

For instance Nöel and Seron hypothesized subjects comparing the Roman numeral XII to the word *twelve* , as opposed to the equation 10 + 2, would have a higher error rate. The team analyzed the variance of error in two within-subject variables, the format (word or Roman) and the response (true or false). When they applied a three magnitude comparison test they found subjects' number words did not activate the same internal representations as Roman numerals. Internal representations of numbers did tend to affect calculation efficiency.

Dehaene (1992, 1997) has presented a theory that suggests two-way transfer of information on number processing pathways. In his triple code theory (1992), visual forms of numbers are used for multiple digit operations and parity. Auditory and verbal forms of numbers, such as those used in multiplication table memorization, are found in written input and output tasks. Analog/magnitude representations are involved in processing of comparisons and estimation. Mental pathways of translation between verbal-Arabic, verbal-analog, and Arabic-analog number forms are two way avenues devised for processing of arithmetic transactions. The Arabic/visual realm of numbers is central to the hypotheses of the study reported here.

The Spatial Linguistic Relationship of Number Sense

Regardless of how the mind processes numbers and calculations, the brain is required to transfer information from language centers concerned with number words, and shape centers dedicated to identifying numerals Each center is located in different hemispheres of the brain. The left hemisphere is the zone of language, calculation and amount recognition, while the right hemisphere houses number shape and orientation. How numbers are recognized, and where they are stored in memory, is central to this report of research findings. Dehaene (1997) provided MRI and PET scan evidence for a location of number and color representation in the right parieto-occipital region of the brain. He offered evidence that the brain recognizes and catalogues numerical information, such as shape recognition, in regions similar to those dedicated to color processing.

In a diverse and broad body of research, individuals have reported imagining numbers in color (Galton, 1883; Simson and McKellar, 1955; and Serone, Presenti & Nöel, 1992). Normally, individuals will process color and shape information in the right hemisphere and then transfer the information through the corpus callosum to the language centers for verbal naming. In studies of subjects who have had their hemispheres surgically dissected, the location for digit and color recognition was determined to be the right hemisphere. Conversely, vocalization of number is processed in the left hemisphere in all but unusual cases (Sperry, 1985; Corballis, 1996). When students are able to visualize numbers in color, or on an imaginary number line during memory tasks and calculations, they may be coordinating words and shapes for more effective numerical processing.

The Interest in Color Number Relationships Develops

A fascination with individuals who imagine numbers in color developed over a century ago when Francis Galton (1883) published a rather whimsical and informal study in *Nature*.. He had interviewed friends and acquaintances about their preference for imagining numbers in various colors or on intricate number lines. The subjects were predominately female and, he said, tended to be more artistic than mathematical. Some subjects reported to be able to perform calculations using curlicue configured or symmetrical number lines. Galton suggested that the school classroom would be the most authentic venue in which to confirm or disprove the value these interesting adaptations of number representation.

Baron-Cohen, Wyke & Binnie (1987) suggested that seeing words in particular colors or "chromatic-lexical" (p. 761) processing was a form of synesthesia, which was effective for use in memory tasks. The subject of their study was a 76 year old female artist who had placed an advertisement describing herself in the British Psychological Society Bulletin. The subject had very specific associations of color for particular regular and proper nouns. She implemented her color word system as a memory device. Psychologists interested in discovering the origin and authenticity of her ability devised a word-color memory test to confirm the claim that she associated colors with every word she heard. She was evaluated for color-word associations on 103 items. The test words included days of the week, names, letters of the alphabet, and fifty meaningful words in five semantic categories. After 2 1/2 months she was asked to repeat her color associations and she demonstrated 100% accuracy of memory for colors associated with the list of nouns and letters.

Seron, Presenti and Nöel (1992) found a similar subject who displayed 'numeric-lexical' synesthesia type associations with equal accuracy. Inspired by Galton's work, the team had undertaken to discover the origin of color number association and the rate at which it occurred. They began with an informal study of relatives and colleagues at the University Catholique de Louvaine in Belgium, to determine if number color associations appeared in the general population . While undertaking these "strange experiments" (p.159) the team surveyed 194 students to determine what role number imagery plays in mathematical reasoning. Of the original 194 subjects, 49 responded affirmatively about using visual number forms. Thereafter, 26 of those subjects agreed to answer an extended questionnaire about their visualization of numbers. Extensive interviews were conducted with those who said they possessed imaginary mental "number forms" (p. 163).

The extended questionnaire elicited information about the subjects' visual representation of number; i.e., shape, color, clarity and structure. Two types of number reasoning schemes were identified: ordinal succession on a number line and number color coding. Although spatial symbols were essential to the subjects' number representations, it was not concluded that those who employed number form representations had a greater tendency to be visual thinkers. Number visualizes did, however, appear to be less verbal. The researchers postulated the subjects, rather than having an enhanced visual ability, were compensating for a language deficiency where rote memorization of number words was difficult. Although the team examined learning style preferences, they did not directly assess the relationship of mathematic ability and number imagery. Neither did they assess their first group of subjects directly for creativity.

Subjects who purported to use visual representations of digits were surveyed regarding how they implemented number forms. Three of their subjects visualized analog forms of numbers, fourteen imagined number lines and seven associated colors with their imaginary numerals. Eleven subjects who reported using number forms relied on them for calculation or memory tasks. A few reported using number forms for simple addition, and two implemented them for division or multiplication .

In a follow-up study, two subjects were selected for extensive interviewing. One female graduate student reported vivid color numbers. She had remarkable ability to recall exact colors for specific numbers over time, similar to the claims of the 76 year old synesthetic artist who reported arranging numbers in a configuration. Both Baron-Cohen and Seron's teams found memory was influenced the most by number color or configuration. The fact that the 76 year old woman was an artist was consistent with the profile of synesthesia that is associated with heightened creativity.

The other subject of Serone et al. (1992,) a seventeen year old senior high school student, incorporated an extensive visual number line for calculations. During a follow-up study, this subject was tested in experiments designed to track length of processing time referred to as "magnitude effect" (p.183). In a three factor ANOVA analysis of the subject's number representations, number distance, direction and magnitude were compared. The team discovered a clear distance effect where more proximal numbers were recalled more quickly ($F_{1.56} = 61.46$; $p = .0001$). Magnitude effect was applicable only to smaller numbers, or not at all ($F_{1.56} = 1.39$). Nevertheless, there was a clear interaction between magnitude and distance ($f_{1.56} = 32.95$; $p<.0001$) The team concluded that subjects used number representations to facilitate number memory and calculation more effectively. Although the subjects appeared to be either highly creative or mathematically talented, those traits were not used as variables in the study. The research focused more on identifying qualities of the visual strategies and assessing their role in memory and calculation.

Do Children with Mathematical and Creative Ability Use Number Color Sense?

Dehaene (1997) suggested that children develop imaginary number and color coordination in response to learning tasks that require memory. He hypothesized that when children begin to learn numbers, part of their lower right parieto-occipital structure assigned to color identification accommodates number shape identification as well. The two tasks, color identification and number identification become melded into one network. Another possibility offered by Seron, et al. (1992) suggests that when children are learning to memorize arithmetic facts, they use color and shape association strategies to catalogue algorithms.

THE PRESENT STUDY

The present study examines the role number visualization plays in mathematical reasoning ability and if there is a relationship between creativity, number imaging and ability. Data is analyzed to determine the prevalence of color and line number forms used by adolescent math students. The purpose of the study is to determine how often number color and line imagery occurs in a particular population, to develop a profile of individuals who use colorful imagery for number representation and to begin to examine how the strategy is effective. Additionally the study is designed to determine whether number color and number line visual strategies develop more in mathematical or creative individuals and if there is a relationship among the three traits.

The goals of the study are as follow:

1. To determine if there is a correlation between visualizing numbers in color and greater mathematic ability.
2. To determine if there is a correlation between visualizing number forms and creativity.
3. To determine if there is a correlation between good mathematic reasoning and more elaborate visualization strategies.
4. To develop a profile of the student who is a number color visualizer: Does he or she possess as much creativity or mathematical ability as it appears from previous research?

To begin to understand the relationships, a set of hypotheses were engineered to determine how number color and line form relates to cognition.

<u>Hypothesis one:</u> There is a relationship between mathematical ability and number color or line imagery. As a result, students who visualize numbers in color or on number lines will tend to have greater mathematical ability or interests.

Hypothesis two: There is a relationship between creative ability and number color or line imagery. As a result, students who visualize numbers in color will tend to have more creative ability or interests.

Hypothesis three: Students who imagine number lines or color numbers tend use visual strategies to solve problems or to express creativity. As a result, visual thinkers will tend to either be more creative and more mathematic in their thinking.

To develop a profile of the student who utilizes the imaginary number colors or number lines, the following question will be addressed: Under what circumstances and for what reasons do students implement imaginary number forms? What is the relationship between number imagination and the use of visual number forms? How is creativity expressed in students who use visual number forms?

METHOD

To determine the relationship between imaginary number forms and mathematic, creative and spatial ability, a survey and two tests were administered to a group of 87 middle school students who were enrolled in algebra and pre-algebra classes. In addition, students' placement in advanced, intermediate or regular math class- as determined by the school district- was used in the comparison to confirm mathematical ability.

The Subjects

The sample consisted of 87 eighth grade students attending a suburban New England middle school. Six students were unable to complete the entire survey and test set and their results were deleted from the analysis. There final sample consisted of 81 students. Students were grouped by class and instructional level, the levels were color coded and each student was assigned a number. The distribution of student was as follows:

Pre-algebra:	yellow	Numbers 101-115	**n=15**
Beginning Algebra:	orange	Numbers 301-317	**n=15**
	green	Numbers 501-516	**n= 25**
Intermediate algebra:	blue	Numbers 201-220	**n=19**
	red	Numbers 401-419	**n=17**

Ages ranged from 12-14 years. Age was not a variable in this analysis.
There were 46 males and 35 females. Gender was not a variable in this analysis.

Placement was a variable in this analysis:
There was greater distribution of students at the more advanced levels of algebra than the introductory level. Pre-algebra students were outnumbered by the other levels at a ratio of $\geq$ 2:1.

The Instruments

A total of eighty one students respond completely to three instruments:
1. A survey of preferences related to math and creativity/imagination.
2. A multiple choice test of mathematical reasoning similar to the COG-AT.
3. A drawing test of creativity, (TCT-DP) with established validity and reliability.

The classroom was visited on four occasions for the purpose of gathering data about mathematical and creative thinking. On the first visit, a multiple choice survey was conducted. On the second visit, a drawing test of creativity was administered. On the third visit, a short math reasoning assessment was administered. During the fourth visit, nine of the students who had demonstrated the preferred trait of visualizing numbers in color, or in number line arrangements, were interviewed in a focus group gathered for the purpose of eliciting responses to a more comprehensive questionnaire.

The Survey

Students responded to the survey after an introduction and brief explanation period. Each group was given ample time to respond thoughtfully. The survey, consisting of twenty-nine questions, elicited responses about behavior in number visualization, mathematic interests and creativity. The survey was designed to evaluate students' personal preferences about mathematic thinking, visual thinking and creative thinking. Students were asked to rate the frequency of each behavior either *almost never, occasionally, often* or *almost always.* Responses were scored with a rating of 1–4; a four indicated the greatest preference for the behavior and one indicated the least. The questions were grouped in three categories: math interests and abilities, creative activities and interests, and use of visualization strategies.

· *The Test of Creativity*

To evaluate creative ability in relation to visual strengths, students completed the ***Test for Creative Thinking Drawing Production***. The test was developed in Germany by Jellen and Urban (1985) to assess creativity in the context of productive, imaginative and divergent thinking. The test consists of a large square border drawn on 8.5X11 inch white page The square encloses a squiggle, a circle, a dotted line and a right angle. Outside the border on the top there is a three sided box. On the right side there is a smaller version of the same figure.

Students are given pencils and are instructed to complete the picture in an allotted 15 minutes. No other instructions are given. Tests are rated for 11 key elements: 1) completion, 2) additions,
3) new elements, 4) connections to an existing line, 5) connections to a theme, 6) fragment dependent and independent boundary breaking, 7) the addition of perspective, 8) humor, 9)

unconventionality and 10) abstraction, and 11) speed. The usual maximum possible score is 72. For the purpose of this study, the speed score was not included. Thus, the maximum available score was 66. Assessment of creativity was based on the elaboration students accomplished during picture completion. In comparisons of traditional intelligence tests and creativity assessments, creativity correlates to ***g*** intelligence only to a threshold point. (± 120) (Getzels and Jackson, 1962). *Intelligence was not a variable in this study.*

In a study of four diverse German middle school groups, whose academic ability ranged from: learning disabled, (S S); low academic achievement, (HS); above average achievement, (GY); to mathematically advanced, (MP), Jellen and Urban reported the reliability of the TCT-DP to assess creativity to be very high. Their study compared creativity in four academic levels and the sample was sufficient enough to produce an analysis of the creativity of the different populations.

Reported Reliability:

	SS	HS	GY	MP
Rank correlation (R)	.88	.96	.88	.90
Multiple correlation (r)	.91	.97	.89	.94

The TCT-DP was selected for the present study because it was reported to be an effective tool for assessing creative thinking through drawing for middle school aged students.

· ***The Mathematic Cognition Test***

Since students were already grouped by math ability, based on standardized test scores and class performance, an additional opportunity to analyze different levels of mathematic ability in relation to creativity existed. For the purpose of assessing mathematic ability, in addition to mathematic achievement placement, a thirty question test of mathematical reasoning was administered. The test was similar to the Riverside COG-AT (Cognitive Abilities Test). The test that was designed for the purpose of this study was expected to have validity and reliability similar to the COG-AT since similar reasoning strategies were to be evaluated with similar types of questions. Reliability of the COG-AT reported by Riverside is:

Grade 8	# of Items	Mean	SD	SEM	KR20
Fall	60	33.42	11.92	3.37	.92
Spring 60	30.98	11.09	3.36	.91	

According to Riverside Publishing, the COG-AT achieves validity in testing a mathematical reasoning ability. Riverside (1992) identifies six areas of validity addressed in full COG-AT test of language, spatial and mathematical reasoning: 1) abstract and general concepts, 2) interpretation and

use of symbols, 3) relationship among concepts and symbols, 4) flexibility in organization of concepts,
5) pattern identification, and 6) abstract reasoning not related to speed.

Since the current study was designed to evaluate imaginary number representation in relation to abstract mathematical reasoning, the ability to perform algorithms, to calculate rapidly and to apply formulae were not germane. How adolescents manipulate numbers visually is essential to the study. Students are taught, and tend to rely on, concrete representations of numbers for arithmetic tasks, although formal operational ability has begun during pre-adolescence (Piaget, 1950).

RESULTS

- **Comparing mathematical achievement, creativity and visual strategies results.**

Of the 81 participants, 22 students reported imagining numbers in color: *almost always* (n= 8); *often* (n= 4) or *occasionally* (n= 10). The number of students who reported using imaginary number lines, *almost always* (n= 4); *often* (n= 14) or *occasionally* (n= 20) was 38. Thirteen students reported using number lines and number color forms *almost always* (n=2),*often* (n=6) or *occasionally* (n= 5).

A simple analysis of variance did not adequately profile students who use imaginary number forms. Nevertheless, it yielded information of some value for comparison about creativity, mathematic achievement and use of visual strategies for problem solving. Out of a possible score of 100% for 16 questions, the mean **mathematic achievement** was **66.172** **(SD 16.74)** The scores ranged from 13% to 93% with a median score of 69%. The most frequently occurring score was 69%. The mean TCT-DP, **creativity** score was **28.28, or 48%** **(SD 9.83)** out of a possible score of 66. The scores ranged form 5-51 (10%-72%) with a median score of 29 (44%). The most frequently occurring score was 36 (55%). The mean score for the seven selected survey questions related to **visual strategies** was **17.79 or 64% 9** **(SD 4.02)**, out of a possible maximum of 28. The scores ranged from 8 to 26 (29%-93%), with a median score of 18 (64%). The most frequently occurring score was 20 (71%).

- **Comparing creativity, visual strategies and number color to placement**.

By performing a univariate analysis comparison of placement to creativity, mathematic achievement and number visualization, a more informative profile was produced. By way of introduction to this analysis, the following data is informative: For the level 33 (pre-algebra) mathematics class, a single student reported using number color. Eight students in the level 66 (beginning algebra) group reported seeing numbers in color *often* or *almost always*. Nine students reported seeing numbers in color in the level 99 (intermediate algebra) group.

In the comparison of placement to math achievement, creativity, visual strategies, number lines and number color and following data were reported:

Mean (SD)	Math	Creativity	Visual	Line	Color
Level					
33	46.26 (19.12)	19.26 (9.42)	15.53 (4.25)	1.6 (.82)	1.33 (.35)
66	68.86 (10.4)	27.66 (8.01)	18.06 (3.88)	1.73 (.94)	1.46 (.89)
99	72.63 (12.98)	32.55 (8.84)	18.50 (3.79)	1.66 (.95)	1.69 (1.14)

- **Chi-square analysis comparison of variables.**

In a Chi-square analysis of the frequency of **number color and number line visualization** reported by students in the three math class placement groups, the following rates occurred:

Percent (n)	Never	Occasionally	Often	Almost always
Level				
33 color	86.67% (n=13)	13.33% (n=2)	0	0
Number line	60.00% (n=9)	20.00% (n=3))	20.00% (n=3	0
66 color	73.33% (n=22)	13.33% (n=4)	6.67% (n=2)	6.67% (n=2)
Number line	53.33% (n=16)	26.67% (n=8)	13.33% (n=4)	6.67% (n=2)
99 color	66.67% (n=24)	13.89% (n=5)	2.78% (n=1)	16.67% (n=6)
Number line	61.11% (n=22)	16.67% (n=6)	16.67% (n=6)	5.56% (n=2)

- **Two-way Analysis of Variance by Placement:**

In an ANOVA comparison of three dependent variables by placement, the results yielded two slightly significant indicators. Naturally the ANOVA results for **achievement** and **placement** yielded a positive relationship. As math achievement increases, placement increases. The Sum of squares was 8278.8 (R–square = 0.36897, f=22.80 p>.0001), indicating a reasonable relationship between placement and achievement.

In the ANOVA comparison of the dependent variable **creativity** to **placement,** it is reasonable to infer a relationship between creativity and mathematic placement. The reported R–square was 0.243, the mean square was lower, (943.99) and the F value was 12.59, with a p. of

>.0001, indicating that the relationship of creativity increased as placement increased[1] . The ANOVA regression analysis for visual strategies and placement was less positive: Mean square 48.41, F value 3.16 and p>.0481.

A discussion of these findings will follow. However, it is important to note here that in an examination of TCT-DP results, creativity scores did increase as placement increased. Please refer to the visual graph following this section.

CORRELATION BETWEEN VARIABLES

For the purpose of this report, correlations are grouped by topic:

Topic one, Visual strengths

	Visual strategies	**Number line**	**Visual preference**
r to category			
Placement	r=+.244 (p>.018)	r=+.013 (p>.905)	r=+.098 (p>.382)
Achievement	r=+.258 (p>.020)	r=+.042 (p>.705)	r=+.033 (p>.768)
Creativity	r=+.194 (p>.082)	**r=–.003 (p>.980)***	r=+. 107(p>.341)
Color	r=+.221 (p>.047)	r=+.270 (p>.014)	r=+.183 (p>.100)

Topic two: Creativity

	Creativity	**Creative pref.**	**Number color**
r to category			
Placement	**r=+.483 (p>.0001)****	r=+.004 (p>.967)	r=+.212 (p>.056)
Achievement	r=+.192 (p>.085)	r= –.020 (p>.858)	r=+.008 (p>.940)
Visual	see above	r=+.136 (p>.225)	r=+. 221(p>.047)
Visual pref.	r=+.107 (p>.341)	**r=+.541(p>.0001)****	see above

[1] Considering these two factors together permits inference that mathematic achievement and creativity are related in this sample.

Topic Three: Survey responses[2]

	Visual preference	**Math preference**	**Creative preference**
r to category			
Placement	r=+.098 (p>.382)	r=+.219 (p>.049)	r=+.004 (p>.967)
Achievement	r=+.033 (p>.768)	r=+.264(p>.017)	r=–.196 (p>.078)
Creativity	r=+.107 (p>.341)	r=–.192 (p>.084)	r=+.106(p>.345)
Color	r=+.221 (p>.047)	**r=–.053 (p>.635)***	r=+.196 (p>.078)
Number line	r=+.241 (p>.029)	r=+.013 (p>.902)	r=+.136 (p>.225)
Visual strategy	**r=+.478 (p>.0001)****	**r=+.602(p>.0001)****	r=+.192 (p>.084)
Creative pref.	**r=+.541 (p>.0001)****	r=+.101(p>.366)	N / A

Topic Four: Correlation for the original hypotheses

	Placement	**Achievement**	**Number color**	**Number Line**
r to category				
Create	**r=+.483 (p>.0001)****	See above	r=+. 223(p>.044)	**r=–002(p>.98)***
Visual	r=+.244 (p>.027)	r=+.258 (p>.020)	r=+.221 (p>.047)	r=+.262 (p>.018
Achvmnt.	r=+.540 (p>.001)		r=+.008 (p>.940)	
Plcmnt.			r=+.212 (p>.506)	

DISCUSSION

Reasonable correlations were found among a number of variables. As noted previously, the relationship between placement and achievement speaks for itself; in this case r= .51, p>.0001. It is reasonable to expect math class placement to follow mathematic achievement. ANOVA results for placement and achievement confirm this relationship. These numbers merely serve to imply statistical significance. From these data it can be assumed that the mathematic achievement test was a reasonably valid instrument, although a higher correlation would be preferable.

The confirmation that the mathematic placements were appropriate for the sample studies permits the use of placement as a independent variable. Placement was used as the independent measure for reliability in further comparisons. The Chi–square analysis served to confirm that

[2] Please see the following section for a discussion of the validity of the survey.

students in the 33, pre–algebra group used number color imagery less in relation to the remaining four groups, although they used number line as a visual strategy as frequently as the remaining groups. There was a clear increase of number color imagery associated with higher placement. From this information, it can be inferred that number color imagery is different from number line imagery. A moderate correlation (+.220, p>.014) does exist overall.

In an attempt to distinguish creativity and mathematic ability in placement groups (33, 66, 99), t-tests indicated a significant difference in both variables for the three. The scores for creativity tests and math achievement varied significantly enough across placement groups to infer creativity and math ability are related in this sample; although the correlation was fairly low (r=+.192 (p>.047). Additionally, the T–test for visual problem solving strategies, in comparison to placement, indicated a significant difference between the 33 group and the 99 group. In all three variable-by placement comparisons, T-test results indicated statistical significance in the difference between the three groups in creativity and visual strategies. The difference between the 66 and 99 groups, however was not consequential for the creativity variable. The same is true for achievement across the three placement levels. The difference between the 33, beginning algebra, group and the remaining two was worth noting.

The T-test results are crucial to confirm that creativity and mathematic achievement increase with placement, as does number color imagery. Where number color use is similar in the 66 and 99 placement groups, it is virtually non-existent in the 33 level group. ANOVA for creativity and placement (F=12.59, p>0001) and achievement and placement, (F-+22.8, p>.0001) confirm the relationship. Indeed, by looking at the number line and visual strategies correlations (r=.2632, p>.074) in comparison to the placement ANOVA result for visual strategies, which is minimal, one can surmise a less significant relationship between number color use and number line visualization. In Chi-square analysis, the rate at which students used number lines by placement did not vary as significantly as the rate at which they saw numbers in color. Visual strategy correlation to placement was moderate (2=.244, p>.018), as well.

Perhaps the most revealing data in this study occurred in the correlation analysis. When considering the hypothesis that students who are more mathematically talented would use color or visual strategies more frequently, the results vary. There is no correlation between mathematic ability and number color imagery (r=.008, p>.948). The use of number line as a visual strategy did not correlate well with mathematic achievement either (r=+.042.,p>.705). Correlations between creativity and number color (r=.223, p>.044), and number line (r=–.002, p>.98) when compared indicate that creative students ***do*** use number colors, and do not use number lines as visual strategies.

Correlative relationships occurred between how students reported their use of visual imagery, mathematic talents and creativity in relation to each other and number color. Students who preferred mathematic pursuits did not report seeing numbers in color (r=.+053,p>.635) They did however, prefer visual strategies for problem solving (r=+.602, p>.0001). Students who reported preferences for using visual strategies also had stronger creative preferences (r=+.541 (p>.0001).

Certain correlations, considered together, reveal a profile of individuals who employ number color and number line in their thinking. Students who uses number line and visual strategy are not as creative ($r=-.003$ $p>.980$) as they are mathematic. Students who imagine numbers in color are a bit more creative ($r=+.223$, $p>.044$) than they are mathematic ($r=+.008, p>.940$) and they prefer visual and creative pursuits to mathematics. Students who report creative preferences also report a stronger visual preference ($r=+.541$($p>.0001$), but less math preference ($r=+.101$, $p>.366$). Correlations are most revealing about the reliability of the survey. In both a comparison of math achievement to placement ($r=+.540$ ($p>.001$) and math preferences to placement ($r=+.219$, $p>.049$) the correlations should have been closer to 100%. The same is true for creative preferences reported on the survey compared to creativity scores ($r=+.106$, $p>.345$).

CONCLUSIONS

Regarding the goal of the study, to find relationships between visualizing number forms and greater mathematic ability, although there is a relationship between mathematic placement and number color use, consistent strong indicators do not exist for these data. Creativity, however, does have a relationship to mathematic ability as well as the use of number color forms. Students who see numbers in color are generally more creative than mathematic. The reliability of the math achievement test and survey results should be considered. The correlation between creativity and mathematic ability was confirmed by placement, however. That relationship should be recognized in future work.

This observation was confirmed in small group interviews where students who had indicated a strong use of number color imagery had overall higher math placement, as well as creativity scores. This is a qualitative observation, however, in that the relationships did not indicate the same robust relationships. In in-depth interviews, certain students who reported a strong use of number color imagery also had high TCT-DP scores, as well as strong visual creative strengths. For a handful of students, a particular creative and artistic ability happened to coincide with the ability to see numbers in color and on number lines. For the most part, those students relied on visualization to remember number information and to perform mental arithmetic calculations. Unfortunately, that particular combination of abilities and talents did not occur in a significant enough proportion to indicate any trend in the population. The goal to develop a profile of the student who imagines numbers in color has been achieved. As Galton and Seron discovered, individuals who imagine numbers in color or number lines represent a small but creative and imaginative proportion of the population.

The hypothesis that there is a relationship between mathematic ability and number forms was not proven. A relationship between creative ability and number color or line imagery was demonstrated, however. Indeed, students who visualize numbers in color tend to have more creative ability or interests as over all. Students who reported visual strategies and preferences tended to employ visual number lines to solve problems. They had mathematic preferences, if not achievement, as well. The data demonstrated that students who imagine number lines or color numbers tend use visual strategies to solve problems or to express creativity. As a result, visual thinkers will tend to be either more creative or more mathematic in their thinking.

The correlation between creativity and mathematic ability should be noted. In future research, creativity should function as the independent variable when assessing efforts to enhance programs that are laden with graphic information such as mathematics, art or computer technology. As a continuation of Galton's and Seron's strange and whimsical work, these limited findings could be added to the overall understanding of individuals who imagine numbers in color.

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