AC 2012-3268: THE EFFECTS OF HANDS-ON ACTIVITIES ON MIDDLE SCHOOL FEMALES' SPATIAL SKILLS AND INTEREST IN TECHNOLOGY-BASED CAREERS

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The Effects of Hands-on Activities on Middle School Females' Spatial Skills and Interest in Engineering and Technology-Based Careers

Abstract

Early exposure to, and training in, spatial activities may lead to heightened interest in STEM subjects, particularly in females who believe they must always excel, and like it when they do. Females continue to be underrepresented in many STEM fields, particularly engineering and technology. This study examines the efficacy of utilizing hands-on activities to enhance spatial abilities and heighten female interest (engagement) in STEM careers. Prior hands-on experience was directly linked to both spatial visualization abilities and career interests of the subjects. More hands-on activities are better; younger may not be better when it comes to encouraging careers. Weak correlations between interest in a career in engineering or technology and spatial visualization skills can be strengthened via practice and encouragement.

I. Introduction

In the early 1980s, females comprised around 15% of engineering graduates; by 2007, nearly thirty years later, that statistic had changed a mere 4 percentage points. Women are approximately 50% of the population, yet a mere 11% of the engineering and technology workforce [1], nearly 40% fallout between college and career.

Why is it that women are notably absent from fields where entry level wages are higher than just about any, and jobs are still to be found? It is not because they are lacking in ability to do the science or math, as the research has shown [2], but it may be because they do not see engineering and technology as a pathway to their desire of making a difference and/or changing the world, or they are struggling with the spatial contexts, among a variety of reasons.

Changing the Conversation helped identify some of the messaging we needed to work on regarding engineering, and also those messages that resonate most with females, particularly "Engineers make a world of difference", and "Engineering is essential to our health, happiness, and safety" [3]. The resultant campaign to bring visibility to engineering as so much more than slide rules and pencil protectors has made some small progress in changing the public's perspective of engineering, but the jury is still out on how big of a difference with females. Is it enough to double the number of females entering engineering over the next several years?

As we consider what it takes to add females to the engineering workforce, so we also need to consider the same for non-academic career paths that lead to apprenticeships and craftwork in traditionally male environments such as manufacturing and construction, again, typically high-paying career options. One of the keys to success in both engineering and technology (E & T) is solid spatial skills. Engineers must be able to virtually "see" the product they are designing in two or three dimensions, while technologists must be able to physically bring the representation out of the design specs into three dimensions, using raw materials and tools.

Women are generally at a significant disadvantage to males with respect to spatial skills, which could be contributing to perceived apathy regarding female participation in E & T. The good news is that spatial skills can be improved through training and effort[4,5], so intervention that encourages spatial learning could be a significant factor in increasing engagement.

II. The Problem

Females continue to be underrepresented in many STEM fields, particularly engineering and technology, due in part to the messaging they hear and see, and mostly due to the discomforting sense of being a stranger in a strange land in a predominantly male workforce. Some say that the tipping point for underrepresented groups to begin to feel less excluded is between 20 and 30% [6], and females in engineering and technology fields hover at half that.

Engineering majors that involve physical sciences have historically tended to be the least popular with females, and, not surprisingly, command the highest pay[7]. Is it possible that females' poorer spatial skills, coupled with the marked certainty that the way would not be easy, has been enough to effectively "manage the herd"? Avoidance is a fairly effective deterrent. Poor spatial abilities had already surfaced as one probable cause for STEM "leakage" in earlier research, besides contributing to avoidance in the first place[8,9].

Females' discomfort with three dimensional building emanates from underdeveloped spatial visualization abilities, as suggested by research at the post-secondary and secondary levels[4, 10]. As their skill level increases through practice, they gain confidence, and begin to apply the learned skills. Female learning is most effective when they feel confident in their ability to master the subject matter, and when learning it adds value emotionally, physically, cognitively, or spiritually [8]. If you have ever had problems reading a map, you can appreciate spatial challenges; if you get lost going around the block, you are probably spatially-challenged. And you are probably female.

III. Literature review

While recent research has addressed the "whys" of females underrepresentation in technology-based careers[13, 14, 2], including gender differences associated with spatial skills[15, 9, 16], research that explores how to address the spatial gap, particularly as related to the use of hands-on technology activities, is more challenging to ferret out. Of particular relevance to this researcher is the correlation between spatial abilities and female interest in technology-related fields such as engineering and manufacturing.

Overview

Women represent nearly half of the college graduates and workforce, yet comprise less than one quarter of the nation's computer science or engineering positions[17], and although females are academically prepared to enter STEM degree programs[2], less than 5% are actually intending to major in STEM fields in college[18].

Are spatial abilities the missing ingredient?

Spatial abilities

Cognitive aspects

Bjorklund and Brown believe cognitive development results from physical play[19], as the learner manipulates tools in pursuit of typically spatial and dynamic games, such as baseball. Newcomber and Dubas posit that spatial cognition is critical to STEM success[20]. In Carole Dweck's later studies, it is especially girls who believe that competence is due to luck or genetics, not effort or ability. Those with growth mindsets (vs. fixed), however, may have some inherent or learned resistance to allowing lack of knowledge or experience preclude them from trying something new, and then trying to get better at it. They develop immunity towards stereotype threat[21, 22].

Biological aspects

Consider the biological elements related to spatial abilities: nature vs. nurture. The most popular is the hunter-gatherer theory wherein females utilized landmarking when gathering and foraging, while males oriented themselves dynamically while in pursuit of game, especially once they started devising and using tools to help them[16]. Although vestigial, this author would characterize it as a default setting that may need to be reset in females.

Additionally, hormones may play a role in "turning on" parts of the brain that may enhance some spatial skills[4], although practice may have a bigger impact. Casey discusses application of Annett's 'bent twig' genetic theory in presenting her study on biological aspects related to spatial abilities[8]. Handedness, in particular homozygotic right handedness (both parents and immediate relatives are right handed) may be a reliable predictor of spatial abilities. Specifically, heterozygotic right handed people (leftie in there somewhere) are more likely to have better spatial abilities. The Institute of Education Sciences recommends that schools incorporate spatial training for all students, which is predominantly beneficial for females[23].

Finally, the evolutionary theory convincingly presents the case for male spatial abilities being tied to the male-male competition and ranging associated with mating, whereas females adopted a low-risk, short-ranging survival mode dependent on spatial memory rather than response time[9].

Gender differences

The differences between male and female spatial ability is one of the most prolific research areas, likely because it is one of the few still significant differences. Mental rotation is the most significant difference[24]. Dweck indicates that females with growth mindsets close most gender achievement gaps[22], and Moe and Pazzaglia believe skills practice and spatial training contribute positively towards addressing the gaps[5].

Testing methodologies

Sheryl Sorby's research in 3-D spatial skills development dovetails with Piaget's assessment that spatial skills are developed in stages: first topological (ages 3-5), then projective (adolescence or later), and finally "people are able to visualize the concepts of area, volume, distance, translation, rotation, and reflection" [2]. It is this stage of spatial development that some individuals never achieve, or only achieve in part. Everyone knows who they are – they have difficulty reading maps, do not play sports or video games, and are clueless as to how to calculate their vehicle mileage. They do not typically make good engineers or technologists without significant effort.

Currently, reliable assessments of spatial skills only really address the first two stages of development, with mental rotation tests, such as the PSVT:R or MRT series, coming closest to appropriately assessing the third stage of development [25]. Third stage assessments really demand a dynamic environment, which is challenging to approximate in two dimensions. In the case of this study, the participants averaged 12 years old, so 2-dimensional assessments were appropriate, with lowered expectations on actual performance (than undergraduate level). As individuals achieve higher spatial stages due to experience and practice, so should the expectations, and the shift to a more dynamic and authentic environment.

Peters, et al redrew the Vandenburgh & Kuse Mental Rotation Test (MRT) series in 1995 because the repeated copying had blurred it so much that the validity and reliability were questionable[26]. The MRT utilizes ten cubes in a specific configuration, which are then rotated on a slightly inclined axis in four separate configurations, of which the subject is to choose the two which are the same as the model. The MRT is a timed test where speed and accuracy are both important.

Intervention vectors

Sorby, et al did a significant amount of work evaluating the types of activities pre-college students should be engaging in to improve their baseline spatial abilities by the time they reach undergraduate level. Most of the activities involved hand-eye coordination. Specifically, they found that the freshmen that were arriving on campus with higher spatial skills benefitted from:

(1) Playing with construction toys as a young child; (2) Participating in classes such as shop, drafting, or mechanics as a middle school or secondary student; (3) Playing 3-D computer games; (4) Participating in some types of sports; and (5) Having well-developed mathematical skills.[4]

Bjorklund and Brown's work highlights the value of physical play in developing spatial skills such as mental rotation[19], while Boakes examines the use of origami in developing spatial skills[27]. Several researchers believe online training is as effective as physical manipulation of materials[4, 28], and others have shown where action video games have helped to close the gender gap with increased time in game[15].

Ray McCarthy captures the essence of why girl-friendly technology education curricula is so important in his assessment that the typical "smash and crash" culture of most technology education classrooms runs counter to girls attitudes about the type of projects they would choose to do, so they just do not participate[29]. Teachers that have been effective are those that offer both options in an inclusive, genderless learning environment[30]. Curriculum content that is more

relevant to middle school girls includes renewable and sustainable energy; bio-technologies, including prosthetics; and artificial intelligence.

Impact on career choices

Wai, Lubinski and Benbow's longitudinal study clearly shows that spatial abilities predict STEM success, and recommend spatial assessments of all students as early as possible to ensure an adequate pipeline, and early intervention where appropriate[10]. Even if that happens, though, stereotype threat can limit career choices[14]: who wants to go where they are not really wanted? With respect to engineering and technology fields, 10% of colleagues are female, not quite enough to tip, so the culture is still a predominantly male culture, and the general attitude is 'live with it, or get out'. So females do, but it is challenging to recruit more females to that environment.

Interestingly, Blickenstaff says "the sciences most strongly identified as masculine [such as physics and engineering] are those that are closely tied to improving economic production and developing weapons, two tasks that male-dominated society has decided are valuable[12]." Changing the messaging is critical to dissociating gender from engineering and science careers, so more females can begin to appreciative the economic benefits of a career in engineering or technology. Barring that happening, why fight City Hall? An individual has to be tremendously motivated to choose to take the less-beaten path. While there is no real economic comparison to technology based careers, females' high language proficiencies do introduce career options that might involve less swimming upstream[13].

Career motivators for females

Abilities vs. interests – why so few?

In "Why So Few", Hill, Corbett and St. Rose highlight the significance of the messaging that girls, especially, hear or need to hear from parents and other influencers about career choices[2]. In several cultures, girls are most influenced by maternal messaging (or lack of it); in others, they are given significant, almost negligent autonomy in making post-secondary education and career choices, because no one is expecting them to be a primary breadwinner anyway.

They just may not be that into engineering and science, and with females, engagement is more effective and lasting if they are interested[31]. Finally, regardless of abilities, spatial or otherwise, or interest, engineering careers seem to be more negatively perceived with respect to work-life balance and community, and the benefits may not be perceived valuable enough to overcome the negatives[2].

Removing female de-motivators for STEM fields

Madison Avenue will probably never change their gender-focused marketing approach because it sells, but changing conversations by modifying the messages about engineering to make them more resonant with females AND males is the first step towards STEM equity[3].

When discussing experiences with pre-college females from a personal perspective, educators must learn to focus on the appealing aspects of engineering, such as problem solving and the design and creation process, not course difficulty or being a social outlier.

Dweck and others have clearly demonstrated that a growth mindset resists stereotype threat better than a fixed mindset, and that being able to see and interact with female role models is an even more efficacious vaccine[22, 32].

Hands-on learning

Rationale for use as treatment

There is clearly an interconnection between manipulating 3-dimensional objects with your hands and cognition, especially if it is a physical concept that is being learned. Being able to observe and physically participate in the translation of an object provides a broader sensory and cognitive experience than may be achieved in a virtual environment[19, 27], although with the continued development of simulation technologies, it may be possible for virtual or online experiences to be as effective[33]. In the absence of such virtual environments, this study was concerned only with physical hands-on activities.

Activity variation

Other than comparing online training to in person experiences, the research was rather sparse in studies that compared one type of intervention activity vs. another, with respect to improving spatial skills. The general sense was that any type of spatial activity or training is better than none, and more is better than less[15, 4, 34, 32]. Research into girl-friendly technology education curricula reveals that secondary girls prefer project-based activities, in small groups, with clear performance rubrics. They also prefer working with other girls (vs. boys or mixed) in non-traditional classes such as technology education, and enjoy the designing aspect more than the utilizing aspect, which is preferred by boys[11].

Summary of literature review

Published material on the subject of gender equity in STEM fields is prolific, particularly as related to cognitive and biological differences between males and females. Recent research has shown that cognitive and biological differences may not be as significant as believed, and that interest in STEM fields, combined with lack of resonance with personal values and goals, may be the primary differentiator for underrepresentation of females in these fields.

Little research is available on the effects of curricular or instructional interventions that are effective in battling the lack of interest or dissonance in messaging, but there are strong indications that early exposure to hands-on learning activities, positive role models, and curricula that appeal to females' interests cannot hurt, and may help in the quest for STEM equity.

IV. Significance and purpose of the study

This study examines the interventional efficacy of utilizing hands-on activities with females to enhance their spatial abilities and interest / engagement in STEM fields of study and careers. Females comprise approximately 50% of the U.S. population – ignoring their potential workforce contribution is a gross oversight in our national quest for technological literacy and competence in an increasingly technology-dependent world.

Using hands-on activities in small group settings that tie to real life is an effective means of teaching technological curriculum that encourages females to get and stay involved in technology coursework past middle school [11]. According to Weber and Custer, delivering female-friendly activities will also benefit males who are interested in many of the same type of activities, and helps influence both genders' inclination towards a STEM-based future.

This researcher's 2006 study indicates that over 80% of female engineers or technologists surveyed (N = 87, mean years experience M =15) experienced one or more hands-on events during their K-12 years, several indicating them as notable occasions.

Acknowledging the link between spatial skills and potential STEM success, coupled with the ability to improve them through practice, led to the following research hypotheses, stated as questions.

1. Do spatial test scores of females, specifically in mental rotation, improve following manual spatial training involving 3-dimensional construction activities?
2. Is there any significant difference in spatial test scores based on the number of treatments or age at treatment?
3. Are females more interested in pursuing engineering and technology based fields of study and careers following manual spatial training involving 3-dimensional construction activities?
4. Is there any significant difference in interest scores based on the number of treatments or age at treatment?

V. Assumptions, limitations and delimitations

All the standard study assumptions about tests measuring what they are supposed to be measuring, reliably, and with high validity, apply here, in addition to limitations and delimitations that could impact the generalizability of results, such as purposeful sampling or no control over participants' prior experiences. This study examines middle school females only, so results may not necessarily be generalized to males or females in other age groups. Additionally, the researcher is not comparing any specific hands-on activities to others, or evaluating whether one type of activity is better than another, rather asking the simple, and general, question: do hands-on activities make a difference?

VI. Methodology

Design of study

The study used a quasi-experimental Solomon four-group design, to help control internal validity due to testing effect. There are two treatment groups and two control groups in this design, with one of each completing pre- and post-tests, and the other completing only post-tests. The treatment groups completed their interventions at the same time over a four hour period, while the control groups completed pre- and/or post-tests over a three week period.

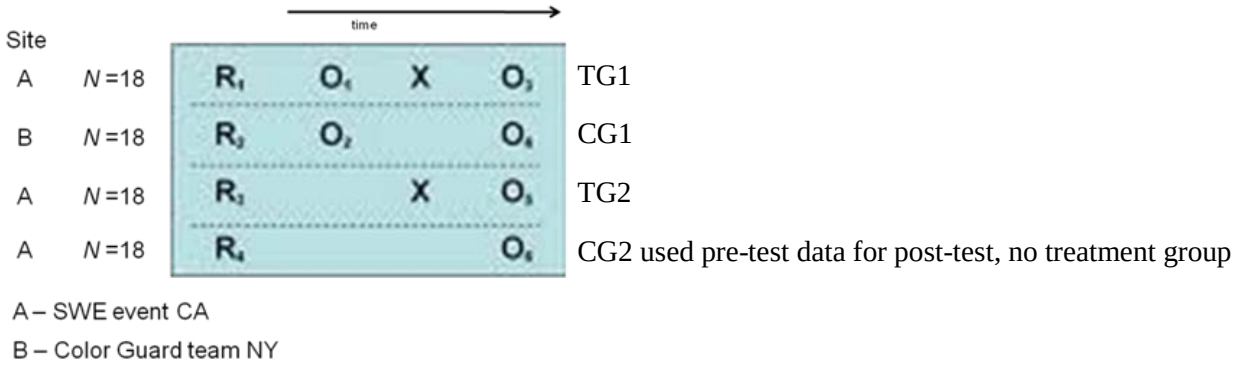

Figure 1. Solomon four group study design.

Participants

Testing was conducted during the school year at two different locations and times. Some information was collected electronically via an online survey. Immediately following pre-testing of one (each) treatment and control group, *N* was 65 for the treatment group and 37 for the control group. Due to control group mortality and to enable ANOVA tests, the final *N* for each group was reduced to 18, for a total *N* = 72.

Samples were drawn from middle school girls at two sites on opposite sides of the U.S. Both treatment groups (TG1 and TG2) and the post-test only control group (CG2) were randomly drawn from participants in a Society of Women Engineers-sponsored event in California. The pre-test, post-test control group (CG1) was a purposeful selection due to the availability of a large group of potential subjects who participated in Color Guard at the NY site, with purportedly minimal experience in technology-based hands-on activities.

Treatment

Treatment (x) consisted of two, 45 minute, 3-dimensional hands-on activities completed over the course of several hours, along with other learning activities that were not hands-on. Overall, there were nearly 200 middle school females, and 50 volunteers, predominantly female, for a four hour period. The activities were 1) to design and construct a vehicle in pairs from readily available household products, that could safely navigate a ramp, and 2) to individually assemble and operate a simple electrical circuit with switch from a kit, using supplied hand tools. The study scope did not include optimizing treatment to effect the biggest change in spatial scores, rather to simply identify and assess the impact of ANY 3-dimensional, hands-on activity.

Testing and instrumentation

For pre-test and post-test for spatial reasoning, this study used Peters, et al. redrawn Vandenburgh & Kuse Mental Rotations Test with 24 items[26] [Appendix A]. Cronbach's α (alpha) reliability for the test instrument is 0.85.

For pre-test and post-test on engineering and technology interest ratings, this study adapted a participant survey from the Society of Women Engineers' Wow! That's Engineering! ™ events for middle school girls. The survey has been in use since 2007, with data collected from nearly 3,000 girls in secondary schools. The specific question that was evaluated was "How interested are you in becoming an engineer or technologist?" with a Likert scale from Not Interested to Very Interested.

Procedure

Pre-tests were administered by the researcher to the pre-test, post-test control group from NY during their after school period (N = 37). A local tester was trained to administer the post-test three weeks later (N = 18). No intervention was applied.

Pre-tests were administered by the researcher to the randomly selected pre-test, post-test treatment group in California as part of an annual technology event in association with the Girl Scouts (N = 65). Participants were asked to return at the end of the day to complete their post-tests; 31 returned (N = 31). The pre-test results that did not have matching post-test results were assigned to the post-test, no treatment group, since they were completed prior to the intervention (N = 34). An additional 28 girls who did not complete pre-tests, completed post-tests after the activities for the post-test only, treatment group (N = 28).

Data analysis

Independent samples t-tests were run to first ascertain that there was no significant differences between pre-test scores for the control group and treatment group, which was in fact the case. Control group pre-test and post-test results were analyzed for significant differences to determine and effects due to pre-test sensitization. To facilitate ANOVA for correlations and interaction effects, the researcher randomly reduced all sample sizes to N = 18, which was the smallest sample size (pre-test, post-test, no treatment). See Table 1 for a detailed guide to the factors that were included in the data analysis.

Variable	Independent	Dependent	TG1 *N* = 18	CG1 *N* = 18	TG2 *N* = 18	CG2 *N* = 18
Age	•		•	•	•	•
Ethnicity	•		•	•	•	•
Prior experience [a]	•		•	•	•	•
Pretest scores		•	•	•		
Posttest scores		•	•	•	•	•
Treatment	•		•		•	
Site [b]	•		A	B	A	A

[a] Expected covariate
[b] Site A is SWE event, Site B is school

Table 1. Factors included in data analysis.

VII. Findings

Introduction

The purpose of this study was to examine the impact that hands-on, 3-dimensional activities have on female middle students' spatial abilities, as measured by Mental Rotation Test scores, and their resultant interest in engineering or technology as a career, based on responses to a survey question. The researcher compared the before and/or after MRT test scores and Q2 responses of students participating in hands-on technology-based activities (TG1 and TG2), to the scores and responses of those not participating in such activities (CG1 and CG2), in addition to comparing post-test results to pre-test results for TG1, and determining if there were any correlations between either of the two dependent variables and the factors of age or number of prior hands-on activities reported.

Demographics

The sample population comprised 72 female subjects – 45% were white and 12% Hispanic, with a mean age of 11.7 years and range from 9 to 15 years.

Pre-test analysis/results

The dependent variables of MRT score and Career Interest rating (Q2) were examined between the treatment group and the control group for pre-tests using *t*-tests. No significant difference was found between TG1 and CG2 in performance on the pre-test MRT scores ($M = 9$, $p = .294$) or Q2 ratings ($p = .287$). Thus, TG1 and CG1 were not considered to have significantly different

spatial visualization abilities or interest in engineering or technology careers prior to the administration of treatment.

Post-test analysis/results

t-tests and analysis of variance (ANOVA) were conducted on the post-test data, in addition to analysis of covariance, using the pre-test results as covariates to the post-test results. Paired one-tailed *t*-tests for independent means on the pre-test vs. post-test scores for TG1 revealed significant differences for both MRT scores and Q2 ratings at the 95% confidence level. Finally, correlation analysis was performed to determine whether the number of treatments or subject's age had any correlation to the dependent variables: spatial visualizations abilities (MRT scores) and interest in technology careers (Q2 rating). See Table 2 for a summary of statistical findings.

Testing	Within groups (post)		Pretest sensitization		Between TG/CG		Correlations
t-tests	CG1/CG2	TG1/TG2	CG1/CG2	TG1/TG2	Both CGs	CG1 only	
MRT	$p = .1271$	$p = .0151$	$p = .1272$	$p = .0797$	$p = .4608$	$p = .2930$	-
Q2	$p = .0002$	$p = .0003$	$p = .0002$	$p = .1747$	$p = .0348$	$p = .0000$	
ANOVA							
MRT	-		$p = .7278$		$p = .9208$		-
Q2			$p = .0792$		$p = .0000$		
ANCOVA			Pretests	Posttests			
MRT	-		$p = .4768$	$p = .2779$	-		-
Q2			$p = .0004$	$p = .0303$			
r_{MRT-Q2}	-.051/.578	.375/-.135	-		-		.259
$r_{MRT/Q2-age}$	.145/-.043	.038/-.07	-		-		.084/-.096
$r_{MRT/Q2-events}$	.568/.414	-.061/.166	-		-		.268/.327

Table 2. Summary of statistical findings.

In summary:

- There was no significant difference between experimental and treatment groups' data for pre-tests, indicating homogeneity of samples, and no pre-test sensitization.
- There were no significant differences within the treatment groups for post-test results.
- There was no significant difference within control groups for MRT scores, although there was a significant difference with respect to interest in technology careers to the favor of CG2.
- There was no significant difference between treatment and control groups for post-test MRT scores, indicating no detectable lift in spatial visualization abilities due to treatment.
- There was a significant difference between TG1 pre-test and post-test MRT scores and Q2 ratings using paired samples.

- There was a significant difference between treatment groups and control groups for post Q2 rating, an indicator of increased career interest following treatment.
- There were weak to moderate correlations between scores on both the MRT and interest survey and number of prior hands-on experiences.

VIII. Summary, conclusions, and recommendations

Did the study do what it was supposed to do? Were the right things measured? There were eight different hypotheses tested related to spatial skills and interest in engineering and technology. Seven of the eight null hypotheses were rejected at a confidence level of 95%, with the lone failed-to-reject somewhat perplexing, but partially explainable by confounding due to the sample selection for the post-only, no treatment control group. The sample was drawn from a population with higher-than-average prior experiences coming in to the survey, which impact is predicted to mildly to moderately skew results.

Conclusions

Hands-on activities do make a difference in spatial skills and interest in engineering and technology careers for middle school girls, and more is better. It is interesting to consider how impact might be isolated to a specific hands-on activity vs. the general combination of the activity, the participants' interest level and prior experiences, and any role model effect. As revealed in prior research, there is a weak to moderate correlation between number of prior hands-on experiences and both interest level and mental rotation test score.

Recommendations

Based on the results of this study, the researcher recommends the following course of actions:

1. Introduce more girls to more hands-on technology activities, earlier than high school.
2. Expand research to further explore the effects of type of intervention and delivery medium.
3. Partner with girl-serving organizations to effect change (funding, role models, activities)
4. Career interest correlation strengthens with age. Nine or ten may be too young to measure career interest accurately. Do activities, but mainly have fun.
5. Replicate study with subjects having lower number of prior experiences (0, 1), to isolate prior experiences interaction.
6. Replicate study with more diverse subjects to enable broader generalization.
7. Explore the relationship between practice and spatial visualizations skills. What constitutes practice, how long and how frequent?

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MENTAL ROTATIONS TEST (MRT-A)

This test is composed of the figures provided by Shepard and Metzler (1978), and is, essentially, an Autocad-redrawn version of the Vandenberg & Kuse MRT test.

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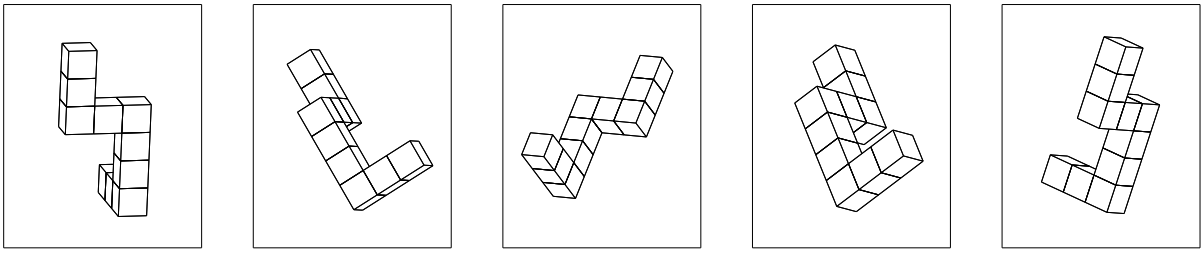
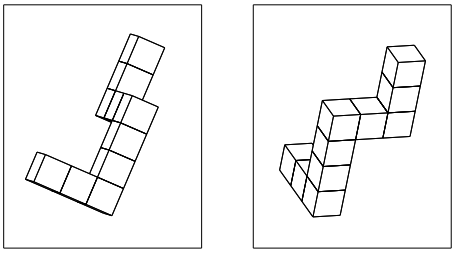
Please look at these five figures



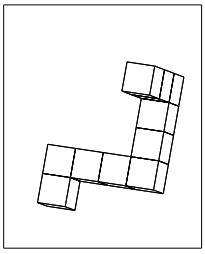
Note that these are all pictures of the same object which is shown from different angles. Try to imagine moving the object (or yourself with respect to the object), as you look from one drawing to the next.



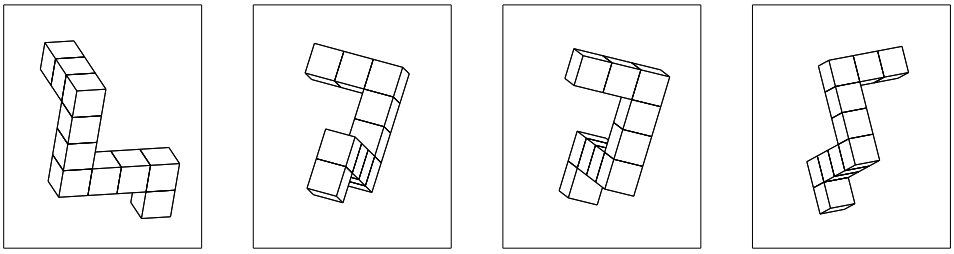
Here are two drawings of a new figure that is different from the one shown in the first 5 drawings. Satisfy yourself that these two drawings show an object that is different and cannot be "rotated" to be identical with the object shown in the first five drawings.

Now look at this object:

1.



Two of these four drawings show the same object. Can you find those two? Put a big X across them.



If you marked the first and third drawings, you made the correct choice.