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# Sex differences in science learning: Closing the gap through animations

Christopher A. Sanchez [a,*], Jennifer Wiley [b]

[a] Arizona State University, United States
[b] University of Illinois at Chicago, United States

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ABSTRACT

Males traditionally outperform females on measures of both visuospatial ability and science achievement. This experiment directly tests a manipulation designed to compensate for such differences through the presentation of relevant illustrations or animations to support the construction of understanding of a specific scientific phenomenon. Males and females read a scientific text about plate tectonics that contained static illustrations, animated versions of the static illustrations, or no illustrations. Participants were assessed on their visuospatial ability and also working memory capacity. Results indicated that while males outperformed females on both the visuospatial measure and overall science learning, the presence of animations effectively eliminated performance differences for this science topic. These results suggest that sex differences in learning outcomes can be overcome by supporting the visualization of scientific phenomena.



## 1. Introduction

Several studies have documented a large disparity between the number of males and females who pursue careers in the areas of science, mathematics and engineering (Benbow, Lubinski, Shea, & Eftekhari-Sanjani, 2000; Ceci, Williams, & Barnett; 2009; Lubinski, Benbow, Webb & Bleske-Rechek, 2006; Spelke, 2005). It has been speculated that sex differences in career choice may be directly related to the fairly robust finding that females perform less well than males on nearly all assessments of visuospatial ability (Halpern et al., 2007; Levine, Huttenlocher, Taylor, & Langrock, 1999). While it has been argued that these differences are likely a result of life experiences, rather than inherent differences in cognitive capacities (Burkham, Lee & Smerdon, 1997; Hyde & Linn, 2006), males often still demonstrate an advantage on spatial skills assessments even when response strategies are considered (Hirnstein, Bayer, & Hausmann, 2009; Levine et al., 2005). To the extent that the physical sciences require dealing with and understanding primarily spatial phenomena (Carter, LaRussa, & Bodner, 1987; Gobert, 2000; Kozma & Russell, 2005; Wu & Shah, 2004), females may be less likely to succeed in these areas due to their lower proficiency at dealing with visuospatial information.

There is evidence consistent with this suggestion: males reliably demonstrate higher performance and interest than females in physical science domains and also on other tasks that share a large visuospatial component (Ackerman, 1992; Burkham et al., 1997; Haertel, Walberg, Junker, & Pascarella, 1981; Halpern, 2004; Hamilton, 1998). While some have argued these effects are statistically small and thus trivial (Hyde & Linn, 2006), it is important to realize that even small differences in a core ability, especially early in one's educational career, can have a profound impact on not only the desire to learn, but also how quickly knowledge is accumulated over time.

### 1.1. Science learning and visualizations

Providing readers with visualizations to support science learning seems like an obvious first step. However, the addition of visualizations to text has led to mixed learning results. On one hand, the addition of static illustrations such as charts and diagrams has been used effectively to enhance science learning (Ainsworth & Th Loizou, 2003; Mayer, Bove, Bryman, Mars, & Tapangco, 1996; Mayer, Hegarty, Mayer, & Campbell, 2005). Similarly, the addition of dynamic animations or video has also been shown to facilitate learning in science (Höffler & Leutner, 2007; Mayer & Moreno, 1998; Moreno, 2006; Moreno & Mayer, 2007; Schnotz, Böckheler & Grzondziel, 1999; Yarden & Yarden, 2010). However, adding visual media does not always facilitate learning, and can sometimes harm it (Chanlin, 1998; Harp & Mayer, 1997; Rieber, Boyce & Assad, 1990; Schnotz & Rasch, 2005; Westelinck, Valcke, Craene, Kirschner, 2005; Wiley, 2003). Further, the potential effects of graphics on learning often seem to depend on interactions with abilities, rather than just the graphics themselves (Geiger & Litwiller, 2005; Hannus & Hyönä, 1999; Sanchez & Wiley, 2006).

The addition of appropriate visualizations should benefit understanding by permitting the reader to redundantly code information in both verbal and spatial memory, and make connections across these systems to increase understanding between conceptual units (Hasson & Sloutsky, 2002; Mayer, 2001). It has also been suggested that visualizations provide additional perceptual cues (Larkin & Simon, 1987), or serve as some kind of external memory system which guides comprehension, further reducing the overall processing demands on the learner (Purnell, Solman

* Corresponding author. Department of Applied Psychology, 7271 E Sonoran Arroyo Mall, Mesa, AZ 85212, United States. Tel.: +1 480 727 1589; fax: +1 480 727 1538.
*E-mail address:* c.sanchez@asu.edu (C.A. Sanchez).

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& Sweller, 1991; Stenning & Oberlander, 1995). Such a reduction should especially benefit those individuals lower in visuospatial ability, as it would supplement and support any deficiencies in their comprehension processes (Hegarty & Steinhoff, 1997; Morrison & Tversky, 2001).

This experiment seeks to directly capitalize on the facilitative effect of conceptually relevant visualizations on learning physical science, with the hope that such visual material will enhance learning and interest for those individuals who demonstrate lower visuospatial ability, and thus reduce any potential discrepancies between sexes that have been observed previously. It is expected that animations will provide the greatest benefit for low visuospatial individuals as they incorporate not only spatial relationships between conceptual units, but also include a dynamic component which better articulates the nature and quality of the interactions between these conceptual units as they change and unfold over time. Additionally, it is expected that static illustrations should also facilitate learning as they provide, at the very least, overt spatial cues for relevant concepts contained in the text.

## 2. Methods

### 2.1. Participants

96 psychology undergraduates from a large Midwestern public university participated in this study for course credit (half male and half female). To control for prior content knowledge or interest, all participants had taken no more than 1 class *total* across 3 content domains: earth science, physical science or geology.

### 2.2. Design

This experiment was conducted between groups in a 2 (Sex) × 3 (Illustration) design with males and females randomly assigned to illustration conditions.

### 2.3. Materials

#### 2.3.1. Visuospatial ability

Visuospatial ability was evaluated using the Paper Folding task (VZ-2, French, Ekstrom & Price, 1963). The VZ-2 task consists of 2 sets of 10 trials in which the participant is shown a diagram of an irregularly folded piece of paper, with all requisite folds marked. Participants are told to imagine a single hole being punched through all the layers of paper at an indicated point, and are then asked to choose between 5 possible responses of what the paper would look like when completely unfolded. Participants have 3 min to complete each set, and the final score on this test was the number of correct responses.

#### 2.3.2. Working memory capacity (WMC)

To control for differences in general cognitive ability (Conway, Kane & Engle, 2003), participants also completed a working memory capacity assessment. All participants completed Operation Span (OSpan) which requires participants to verify simple mathematical operations while also trying to remember unrelated words. The operation–word strings were presented in sets of two to five trials. Three trials of each set size were presented, and set sizes were presented in a random order. In addition, in order to ensure that participants were attending to the processing task, an 85% accuracy criterion on the math operations was required. Administration and scoring followed the recommendations in Conway et al. (2005).

#### 2.3.3. Text and illustrations

Participants read a lesson that was approximately 3500 words long about volcanic eruptions and was presented by computer in 8 separate pages. The text was based on information from the USGS "This Dynamic Planet" unit and the NASA Classrooms of the Future "Volcanoes" unit, originally developed by Wiley (2001). The text contained information about plate tectonics, location of existing volcanoes, types of plate boundaries, chemistry and volcanoes, and also types of volcanoes. It included 5 major concepts from a causal model of volcanic eruptions: (1) heat currents cause plates to move and interact, (2) oceanic plates subduct beneath continental plates, (3) continental plates melt into viscous gaseous magma, (4) more buoyant than surrounding magma, new magma fills magma chambers, (5) pressure builds in magma chambers and is released. Additionally, the texts were presented with static illustrations, animations, or no illustrations depending on condition. Illustrations were chosen to be complementary to the text and to demonstrate the information already contained within the text. The animated versions consisted of either animated GIFs or Macromedia Flash movies that were identical in perspective and reference to the static illustrations, but showed sequences by moving parts of the diagrams. The presentation and positioning of the text was constant across conditions. Any illustrations/animations were presented next to the text and were able to be enlarged and viewed full screen by participants clicking on the image. A screen print is available in the Appendix.

#### 2.3.4. Learning measures

Learning was evaluated using 2 measures: an essay response and a Sentence Verification Task (SVT).

The SVT was a measure designed to test participants' memory for the exact text that was read. In this recognition task, participants were asked to only identify those sentences which actually appeared in the text, thus testing their memory for the surface characteristics of the text. As in Wiley and Voss (1999), false items were created by replacing words or phrases from the original text. This replacement also made those items conceptually false or inconsistent with the text. The SVT was comprised of 20 sentences, 10 of which were exactly as they had appeared in the text, and 10 that were changed. Participants were awarded points for correctly identifying the actual sentences that had appeared and for correctly rejecting sentences that did not appear. An overall score (with a maximum of 20) was computed to form the SVT score. Some sample SVT items are: when plates are separating it is called a transform boundary (False; divergent). Oceanic crust is made primarily of a rock called basalt (True).

The essay response to the question 'What caused Mt. St. Helens to erupt?' was designed to capture overall comprehension of the text. Importantly, the text itself does not explicitly mention the circumstances of the eruption of Mt. St. Helens. Thus, successful completion of this essay task required participants to not only develop an understanding of different kinds of volcanic eruptions, but also identify which of these instances applied specifically to Mt. St. Helens. For this exact reason, this measure is considered to be more complex, and require more reasoning using acquired knowledge, than the SVT.

Each causal essay was evaluated for the presence of the 5 main concepts. For every causal concept included in the essay, participants were awarded a single point. These points were then aggregated to form an overall score on the essay. Points were only awarded for those concepts used correctly and that fit a rubric based on prior work using these materials (Sanchez, Wiley & Goldman, 2006). 2 independent coders randomly scored half of the essays with a high degree of inter-rater reliability (Cohen's $\kappa = .74$; $r(48) = .94$; $ps < .05$). Any differences in scoring were resolved through discussion and the remaining essays were scored by a single coder.

#### 2.3.5. Interest and background measures

A short survey requested demographics and background information on science courses taken. It also included a 1–10 interest scale (with 1 meaning lowest) which participants used to rate the question, "How interesting is the material in this site?".

### 2.4. Procedure

After signing informed consent, participants completed the VZ-2. Participants then read the website about the causes of volcanic eruptions for 15 min. Participants were instructed to read the entire site and not skip any pages or information. Participants were warned when they had 7 min to finish reading, and also again at 3 min remaining. Participants were then asked to complete the task booklet which contained the essay task, SVT and the background survey (in that order). This entire session took no longer than an hour. WMC was assessed in a separate half-hour session.

## 3. Results

### *3.1. Sex differences in spatial ability and general cognitive ability*

To test whether the sexes or illustration conditions differed, a 2 (Sex) × 3 (Illustration) ANOVA was performed for each of these ability tests. Post-hoc comparisons were conducted using Fisher's LSD procedure. Descriptive statistics for theVZ-2 and WMC tasks by sex are presented in Table 1.

There was a significant main effect of sex on VZ-2, $F(1, 90) = 5.30$, $MSE = 11.97$, $\eta_p^2 = .06$, $p < .05$, such that males significantly outperformed females. Importantly, there was no main effect of illustration condition ($F < 1$), nor an interaction between illustration condition and sex ($F(1, 90) = 1.21$, $MSE = 11.97$, $\eta_p^2 = .03$, $p > .05$). This suggests that the differences between sexes were consistent across illustration conditions.

For WMC, there was no significant main effect of either sex or illustration condition, and also no interaction between sex and illustration group (*F*s < 1). This indicates that participants were matched on WMC and that any subsequent differences are not due to general cognitive ability.

### *3.2. Effects of illustration conditions on learning and interest*

For the SVT, there was a significant main effect of sex, $F(1, 90) = 10.55$, $MSE = 4.70$, $\eta_p^2 = .11$, $p < .01$. Males correctly remembered significantly more sentences than females. There also was a main effect of illustration type on recognizing sentences, $F(1, 90) = 3.32$, $MSE = 4.70$, $\eta_p^2 = .07$, $p < .05$. The animation condition outperformed both the non-illustrated and static illustration conditions. Although there was unexpectedly good performance among males in the non-illustrated condition as shown in Fig. 1, the interaction between sex and illustration condition was not significant, $F(1, 90) = 1.88$, $MSE = 4.70$, $\eta_p^2 = .04$, $p > .05$. A speculative interpretation of this trend is that in some cases introducing images might compete with attention to the text, which could impair performance particularly on the sentence verification test.

More importantly, both main effects and a significant interaction were found for the comprehension measure. Males included significantly more correct causal concepts in their essays than did females $F(1, 90) = 11.76$, $MSE = 1.28$, $\eta_p^2 = .12$, $p < .01$. There was also a main effect of illustration condition, $F(1, 90) = 3.48$, $MSE = 1.28$, $\eta_p^2 = .07$, $p < .05$. Post-hoc tests indicated no difference between the non-illustrated and static illustration conditions ($p > .05$), while animations produced significantly better learning than the other two conditions (*p*s < .05).

Finally, there was also a significant interaction between sex and illustration condition on comprehension, $F(1, 90) = 3.43$, $MSE = 1.28$, $\eta_p^2 = .07$, $p < .05$. Males included significantly more causal concepts than females in both the non-illustrated ($p < .01$) and static illustration conditions ($p < .01$). However, males did not outperform females in the animated condition ($p > .05$), and overall performance was at the highest level.

**Table 1**
Descriptive statistics for ability measures by sex.[a]

| | Working memory | Visuospatial |
|---|---|---|
| Overall | .65(.13) | 11.10(3.54) |
| Males ($n = 48$) | .66(.13) | 11.92(3.39) |
| Females ($n = 48$) | .65(.13) | 10.29(3.52) |

[a] *M* (SD).

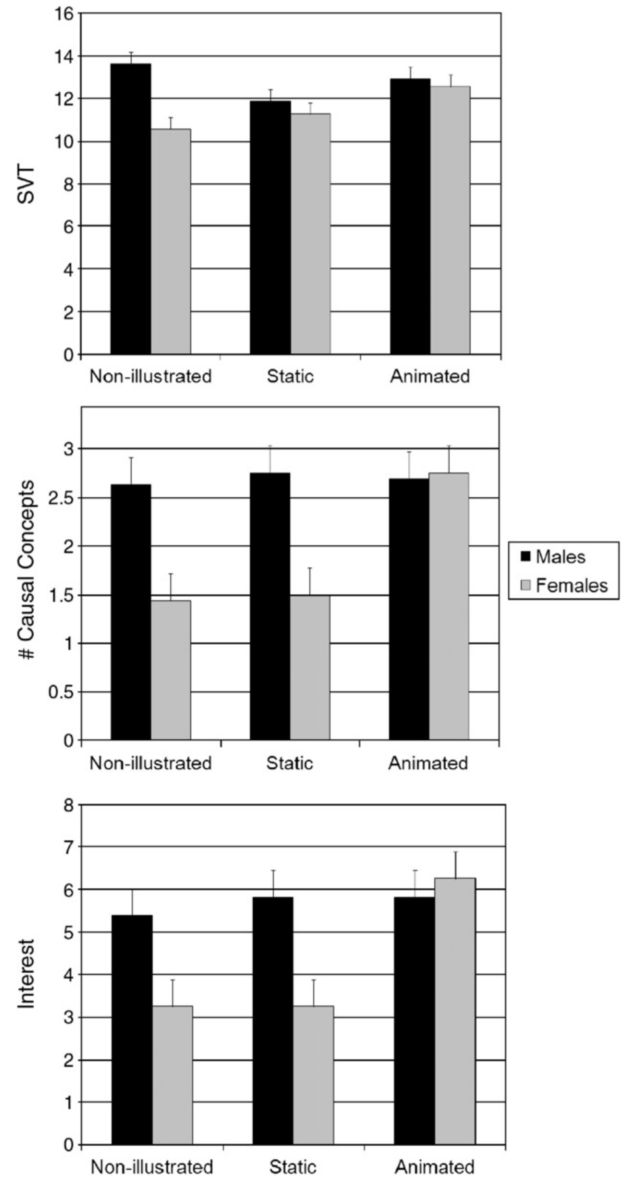


**Fig. 1.** Sex by illustration condition on learning and interest responses. Error bars represent the standard error of the mean ($n = 16$ males and females in each illustration condition).

In an effort to understand how including animations specifically facilitates understanding plate tectonics concepts in females, the frequency of recall for each causal concept was examined. Performance in the non-illustrated and static conditions was aggregated and then compared to the animated condition. Results indicated that the concepts of 'moving plates' ($F(1, 46) = 6.70$, $MSE = .19$, $p < .01$), 'plate subduction' ($F(1, 46) = 4.23$, $MSE = .16$, $p < .05$) and 'pressure' ($F(1, 46) = 11.39$, $MSE = .21$, $p < .01$) were learned significantly better by females in the animated condition than in the other conditions. There were no reliable differences on the remaining concepts.

The pattern of interest in learning about this science topic was identical to the comprehension measure. Overall, males were more interested than females ($F(1, 90) = 7.45$, $MSE = 6.46$, $\eta_p^2 = .08$, $p < .01$). There was also a main effect of illustration condition on interest ratings, $F(1, 90) = 4.33$, $MSE = 6.46$, $\eta_p^2 = .09$, $p < .05$. Post-hoc analyses again found that while there was no difference between the non-illustrated and static illustration conditions ($p > .05$), participants rated the animated condition as significantly more interesting than the other 2 illustration conditions (*p*s < .05). Finally, there was a significant interaction between sex and illustration condition,

$F(1,90) = 3.25$, $MSE = 6.46$, $\eta_p^2 = .07$, $p < .05$. While males were significantly more interested than females in the non-illustrated ($p < .05$) and static illustration conditions ($p < .01$), there was no difference between males and females in the animated condition ($p > .05$).

## 4. Discussion

This study replicated typical sex-linked differences in spatial ability, and also documented differences in both interest and learning from a non-illustrated science text on plate tectonics. Importantly, the current study also demonstrated that these differences can be eliminated by adding relevant animations, and that animations may facilitate learning specifically for individuals with low spatial ability. This result offers an extension and clarification of previous studies showing facilitative effects of animations on science learning (Ainsworth & Th Loizou, 2003; Hegarty, Kriz & Cate, 2003; Moreno & Mayer, 2007; Schnotz et al., 1999; Tversky, Morrison, & Betrancourt, 2002).

Offering support for visualization processes through animations led to equivalent learning outcomes among males and females. It is likely that the external presentation of spatial changes over time reduced the demand on learners to construct these representations themselves, and could also have highlighted important relationships between the spatial elements (Fischer, Lowe & Schwan, 2008). This suggests that animations may be particularly effective for enhancing understanding of concepts that involve change over time. If one examines the specific science concepts that were learned better by females in the animation condition, this seems to corroborate this intuition. For example, the concepts of plate movement and subduction are obvious spatial concepts that include the interaction and change of spatial units (in this case tectonic plates) over time. The concept of pressure also includes an indirect temporal component, as pressure builds and increases over time. Thus, it appears that animations may produce the greatest benefit when used to demonstrate spatial phenomenon that also include a temporal component.

A further benefit of including dynamic visualizations was that they also eliminated the discrepancy in interest ratings. This is especially encouraging considering that interest can be considered a gateway for further exploration into the content area (Steinmayr & Spinath, 2009). For example, if early learning in science were supported by appropriate visualizations, then females might experience more equivalent science achievement, greater interest in science, and an increased desire to pursue advanced degrees in science. It has been demonstrated that adolescents who exhibit higher visuospatial faculties exhibit a stronger preference to pursue and excel in STEM careers and curricula (Webb, Lubinski, & Benbow, 2007). Consequently, this suggests that supporting these processes for students who are not so visuospatially proficient at the critical early stages in their academic careers could provide a similar facilitative benefit and could provide much needed human capital in fields related to science and technology (Halpern et al., 2007).

In conclusion, the present results show that possessing better visualization skills is related to better science learning, and suggest that supporting such skills with animations can be a powerful means of maximizing performance across all individuals, regardless of sex. Two limitations of the current study are the investigation of only a single earth science topic, and that only two kinds of visualizations were utilized (a single static versus an animation). There are several alternative visualizations that might also be used to test whether illustrations that preserve spatial and temporal information are critical for the present findings. One likely candidate for future investigation is presenting readers with each of the frames from the animations, in static form (i.e., a series of images like a filmstrip) which based on previous studies may show similar benefits to the animations used here (Hegarty, 2005; Mayer, Deleeuw, & Ayres, 2007).

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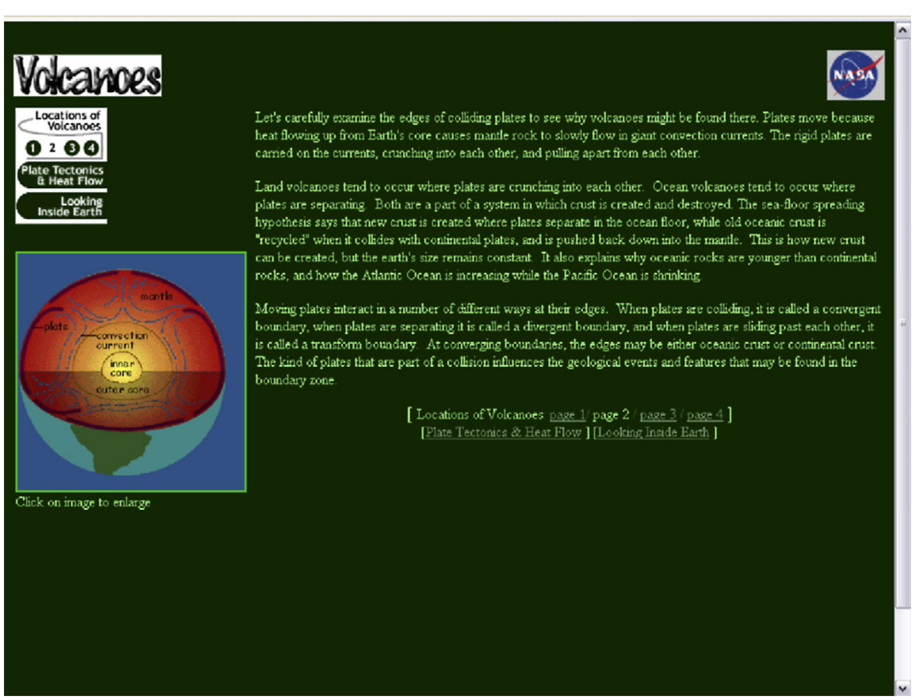
## Appendix

Sample interface:



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