Where is the 21st Century Marie Curie? A Cross-Cultural Perspective on Adolescents' Mathematics and Science Career Choices

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Abstract

In recent years, several reports have been issued by business, education, and government identifying the under-representation of women in quantitatively-based occupations as an urgent issue in education and the workforce. In 2003, 17.9% of doctorates in physics were awarded to women, and 17.0% in engineering (NSF, 2004). Although these numbers represent increases of 6.6% in physics and 6.1% in engineering in the past nine years, they demonstrate the urgency of the problem. Although females graduate from high school with skills and knowledge comparable to males, few of them choose a career in quantitative fields. The causes for these choices are unclear. Researchers agree that the causes are likely to be found in the interactions between biological (e.g., genetics, sex hormones, lateralization) and environmental factors (e.g., individual differences in socialization experiences, prior test performance, personality, self-efficacy, sex-role stereotypes, stereotype threat, interest in science, role-models, teacher and parent expectations, number and types of courses taken, etc.). The present study will examine several important variables that are involved in this complex interaction: visual-spatial cognition, psychosocial experiences, personality, and motivation in a Swiss and American cultural context. I will translate the survey that I have devised for the American sample and collect data in Switzerland during the summer. This will allow me to compare the data with those collected in the United States in order to identify how, among other variables, culture influences adolescents' career decision making.
I. Statement of Problem/Purpose

Society is becoming increasingly scientific, technological, and knowledge-based, depending on the utilization and maximization of human talent and potential. Much attention is being focused on strategies for increasing the number of science, technology, engineering and mathematics (STEM) professionals and for increasing the possible untapped pools of talent. For policies to be effective, they need to build on knowledge about what it takes to become excellent in STEM areas and why women are underrepresented in those fields. In 1995, 18.5% of engineering students were women; in 2005 they were 17.2% (National Science Foundation, 2005). In 1997, women earned 22.6% of Ph.D.s in physics; in 2004 they earned 25.9% of them. A similar trend can be observed in the European Union: in 2003, 33.0% of the science students were women, 31.6% of the students of mathematics, and 17.1% of the students in engineering (European Commission, 2006). Switzerland and Japan show the lowest number of female students in the sciences (15%) (Office Fédéral de la Statistique, 2006). This is rather surprising as Switzerland is the country with the most patents per capita. This underrepresentation of women is problematic because it leads to inequities at all levels of the decision making process. Why are not more of our brightest females pursuing careers in math and science? Is a lack of women in these fields a consequence of less ability – or simply less interest? Put another way, is society holding girls and women back or are they just not interested or intellectually equipped?

The proposed research will explore the hypothesis that the interaction of certain visual-spatial, motivational, and psychosocial experiences could explain important aspects of the female underrepresentation, and that these relate to gender-related differences in learning and educational experiences which affect student performance and interest for science careers. The current study will investigate the gender-linked psychosocial, motivational, personality, and cognitive factors of Swiss and US adolescents that may inhibit interest in scientific careers.

II. Significance of the Problem

In January 2005, president of Harvard University Lawrence H. Summers made news headlines, when he suggested that the dearth of female professors in science and engineering may be due to some biological sex differences in mathematics and science aptitude. His remarks drew a lot of controversy, but they also made the debate of the underrepresentation of women in STEM fields a national one.

In 2003, the National Science Board sounded an alarm about critical workforce shortages in jobs that require high-level mathematical and science skills. This shortage has fueled concern that the United States will not be able to maintain its leadership in science and technology, which translates directly in an inability to fill positions that are essential to homeland security. Similarly economists predict that this shortage of workers with science and math skills is dampening our economic growth and posing a major threat to the economic well-being (Halpern, Benbow, Geary, Gur, Hyde, & Gernsbacher, 2007). If significant populations are not represented, the results may range from being simply inadequate to potentially dangerous to some subpopulations. For example, Margolis and Fisher (2002) outline many of the design problems that stemmed from all (or predominately) male design teams, including voice recognition systems that could not "hear" women's voices, video conferencing systems that ignored women for the same lack of "hearing," automotive airbags designed for male-sized humans that injured and even killed many women, and artificial heart valves sized for the male heart. Gender biases are still evident in gender gaps at many stages of the STEM educational continuum. By comparing two cultures, this study will help identify how different educational systems and other cultural issues influence adolescents’ perceptions about science careers. The only cross-cultural studies in this field compare young students’ performance in the sciences and mathematics (e.g., Program for International Student Assessment, PISA), but few researchers have examined how motivational, educational, personality, and visuo-spatial abilities combine with culture to affect possible career choices.
III. Summary of Pertinent Literature

Cognitive Processes. Studies have consistently shown that, despite the equivalent overall intellectual capacity of males and females, males outperform females on certain tests of visual-spatial ability (e.g., mental rotation, judgment of line angle, water-level tasks, etc.) (Cherney & Collaer, 2005; Cherney & Neff, 2004; Halpern, 2000; Voyer, Voyer, & Bryden, 1995). The causes of these cognitive sex differences and how they relate to science education are unclear. However, it is important to investigate the origin of these differences, because visual-spatial skills are an important element in performance on tests like the SAT-M (Scholastic Assessment Test – Mathematics subtest) and the Quantitative Reasoning subtest of the GRE General Test, particularly for females (Casey, 2001; Gallagher & De Lisi, 1994; Gallagher, Levin, & Cahalan, 2002). Casey, Nuttall, and Pezaris (1997) found that these skills (in particular mental rotation) are a strong mediator of gender differences on the SAT-M. Lower performance on these standardized tests can serve as a deterrent to pursue quantitative careers.

Researchers contend that visual-spatial skills develop over time and that certain real-life experiences foster the development of these abilities. From early toy choices (Etaugh, 1983), to outdoor play (Bjorklund & Brown, 1998), to frequent sports and video/computer game activities (Cherney & London, 2006; Subrahmanayam & Greenfield, 1994), significant correlations between the amount of individuals’ spatial playtime and performance on several measures of spatial abilities has been found (Brown & Bjorklund, 1998; Cherney & Rendell, submitted; Connor & Serbin, 1977; Terlecki & Newcombe, 2006). Because females have been shown to have fewer out-of-school spatial experiences than males (Baenninger & Newcombe, 1995), many females may never tap their potential to think spatially unless spatial thinking is specifically taught within the school curriculum. This is important because, successful problem solving often involves using visual-spatial strategies. For example, when solving calculus and advanced geometry problems, a visual-spatial strategy is more likely to yield mathematical insight than a verbal rule-based strategy. An optimal strategy is to visualize the object as the problem solver builds a representation of the problem as a means of identifying the desired solution state (Halpern, Wai, & Saw, 2005). In a study comparing gifted junior high school and undergraduate students’ ability to solve nuclear physics problems, Cherney and Cherney (2005) found that, although cognitively equally capable of solving the problems, younger students tended to use lower levels of Blooms’ (1956) taxonomy and were less likely to use pictorial representations of the problem. The findings showed that novices benefited from a well-defined problem and exposure to a second method of solving a problem.

Gallagher and DeLisi (1994) collected data on problem-solving strategies by observing high-scoring students as they worked on SAT-M problems. They found that males outperformed females on novel problems, but females outperformed males on conventional problems. Males used more novel approaches to solve the problems, whereas females more often used an algorithmic approach. Similarly, males tended to use more successful and different strategies when solving mental rotation (Cherney & Neff, 2004) and judgment of line and angle position problems (Cherney & Collaer, 2005). These findings suggest that introducing differential (novel) problem-solving approaches and methods might particularly benefit females.

Visual-spatial performance can be improved with training. Baenninger and Newcombe’s (1989) meta-analysis confirmed that both males’ and females’ performances benefit from training experiences. For example, play with three-dimensional computer games have been shown to improve visual-spatial skills (Cherney & Rendell, submitted; Greenfield, 1994; Greenfield, Brannon, & Lohr, 1994; Okagaki & Frensch, 1994; Subrahmanayam & Greenfield, 1994; Terlecki & Newcombe, 2006). Parameswaran and De Lisi (1996) showed that the gender differences on the water-level test in a learner-guided instructions group disappeared, but not in a verbal group, suggesting that verbal learning does not improve scores. Studies have also shown that a brief exposure can produce significant changes. For example, when men and women were exposed for two minutes to another pencil-and-paper rotation task (cube rotation test), the gender differences on the Vandenberg & Kuse (1978) mental rotation test disappeared (Cherney, Jagarlamudi, Lawrence, & Shimabuku, 2003). These and other training studies indicate that environmental factors play an important role in the development of visual-spatial sex differences.
Psychosocial Factors. In addition to spatial abilities, differences in test performance also involve other cognitive processes. It is proposed that some of these cognitive differences could stem from affective factors that may overlap and interact with each other, such as self-efficacy, self-confidence, stereotype threat, and personality. Self-efficacy beliefs are context-specific evaluations of the capability to successfully complete a task and are formed through mastery experiences (past performance), vicarious experience, social/verbal persuasion, and interpretations of physiological and emotional states (Bandura, 1995). In general, females perceive spatial and mathematical tasks as masculine and are more intimidated by them than are males (Meyer & Koehler, 1990). Males tend to have a more positive assessment of their own math abilities than do females (Caplan & Caplan, 2005; Reis & Park, 2001). High SAT-M scorers tend to have high confidence in their math abilities and are persistent when unable to solve math problems immediately (Gallagher & DeLisi, 1994). This highlights the relevance of self-efficacy as a variable mediating sex differences in math test performance.

Females’ self-efficacy and self-confidence about their spatial and math abilities tend to decrease over the teenage years, coinciding with the math competencies shift described above (Hyde, Fennema, & Lamon, 1990). The connection between self-efficacy and ability is important. Students are more likely to enroll in optional math and science courses when they perceive themselves to possess high ability or feel confident in the subject matter. Thus, females might omit to choose optional math classes that in turn might lead them to have less experience with visual-spatial skills and lower self-efficacy. Cherney and Collaer (2005) showed that math experience (as measured by the number of courses taken) contributes significantly to the variance in visual-spatial performance. As males’ and females’ experiences begin to diverge, this could influence other variables, such as attitudes, effort, and interest, which could in turn sway outcome and influence subsequent quantity and quality of experience.

Females have also been shown to be sensitive to implicit cues. Inzlicht and Ben-Zeev (2000) found that, when participants completed a difficult math test in the presence of two other people, women who took the test with two men obtained lower scores than women who took the test with one or two other women. In fact, the women’s deficits in performance increased as the number of males in the group increased. This supports the notion that, when sex differences emerge, they do so within the context of a rich social structure ripe with stereotypes. These gender-based cues are minimized in single-sex school settings. Research suggests that females in single-sex high schools have significantly higher science self-concept and lower science trait anxiety than females in coeducational settings (Cipriani-Sklar, 1997). In addition, single-sex schools minimize may mitigate some effects of stereotype threat. Brown and Josephs (1999) found that women who believed that a math test would indicate whether they were especially weak in math performed worse on standardized math tests than did women who believed it would test whether they were exceptionally strong. In contrast, men performed worse when told that the test would indicate whether they were exceptionally strong. In the absence of individuals of the other sex in the classroom, these implicit cues are probably minimized. It is therefore possible that, for females, single-sex, or home school settings might be particularly beneficial in terms of promoting interest in math and science topics.

Society/Culture. Western societies tend to value scientists, and to think of the field as masculine (Meyer & Koehler, 1990). This gender schema, a cognitive structure that organizes an individual’s gender-related knowledge, preferences, beliefs, and attitudes, begins very early in childhood. According to Martin and Halverson (1981) as soon as children have the ability to label themselves and others as males or females, they are ready to respond to and categorize information on the basis of culturally reinforced gender roles. Because children live in a sex-typed world, this process results in schemata that guide the choices of “sex-appropriate” behaviors and the knowledge of the action patterns necessary for carrying them out (Cherney, Harper, & Winter, 2006; Poulin-Dubois, Serbin, Eichstedt, Sen, & Beissel, 2002). Because of the under-representation of females in sciences, there are few female role-models that adolescents can emulate. However, because cross-cultural research has not been conducted in many settings, little is known about how gender schema and efficacy might operate in other cultures. Furthermore, there is a need for further exploration as to how aspects of culture might influence efficacy beliefs. According to Eccles’ (1984) expectancy/value model, children’s and adolescents’ competence beliefs, self-schemata,
and subjective task values are crucial motivational predictors of performance and choice. These in turn tend to be based on previous performance at a given activity, and on the feedback they receive from parents and teachers.

Cross-cultural studies have generally found that males outperform females in mathematics and science and have higher mathematics self-efficacy (Halpern, 2004). Of particular interest, however, is the finding that the size of the gender difference varies with the status of women in the countries studied (Penner, 2003). For example, the gap is larger in East Asian countries such as Japan and Taiwan where there is a greater emphasis on traditional gender roles than in the United States (Evans, Schweingruber, & Stevenson, 2002). Interestingly, East Asian females, although they lag behind males in their own countries, they score higher in math than males of many other nations, including the United States (Evans et al., 2002). For example, Japanese and Singaporean females score significantly higher than US males on math tests. The under-representation of women in scientific careers has also motivated the European Union to adopt the Women and science – Mobilizing women to enrich European research resolution (The European Commission, 2002). The document describes governmental policies of 30 European countries that seek to increase female participation in the sciences. All participating nations struggle with similar issues as those described above. However, it is interesting to note differences in those issues between and within the countries. In Iceland, although it was the only country where 15-year-old females significantly outperformed same-age males in mathematics and problem-solving among the PISA (Program for International Student Assessment, 2003) study, females are still under-represented. In Belgium, females represented 38.3% of the Flemish-speaking scientists and only 17.3% of the French-speaking scientists, suggesting cultural influences in career choices. Similarly, in the United States, 78% of doctorates earned by Asian/Pacific Islanders in 2001 were in science and engineering fields whereas only 7% of the doctorates were in education (NSF, 2004). Other ethnic groups showed fewer differences. These data suggest the powerful role of culture in the social construction of math performance and that there are important cultural factors that need to be identified. Thus, the present study proposes to compare samples from the United States and Switzerland. Swiss students consistently rank at the top of the Program for International Student Assessment (PISA, 2003). I am planning on matching the Swiss sample with the existing U.S. data that were collected previously.

IV. Research questions/hypotheses

This study will try to answer some of the following questions: (a) Do adolescents who want to pursue math and science careers differ in personality or motivation from those who do not wish to pursue a scientific career? (b) Are adolescents in single-sex schools more likely to pursue scientific careers than those in coed schools? (c) What variables influence adolescents’ career choices? (d) Are these variables different between Switzerland and the United States and if so, why? (e) Can previous and current spatial abilities account for the different career choices? (f) Can differing cultural values account for differences between the countries?

V. Design and Methods

Design of Study

Participants

The goal is to recruit 150 male and 150 female adolescents between 14-19 years from Swiss-German high-schools. Great care will be taken to match the Swiss sample by age and ethnic group to the existing US sample. I am also hoping to match SES and type of school (coed and single-sex schools). I have made preliminary contact with several schools.

Materials

The existing survey that includes questions on previous spatial experiences, past play behaviors, math and science courses taken, career interests, understanding of science, type of schooling, personality
inventories, self-esteem, efficacy, locus of control, achievement motive, the BEM sex-role inventory, tolerance for ambiguity, etc. will be translated into German by myself and a Swiss professor and re-translated into English for reliability. Students will also complete the Mental Rotation Test (MRT; Vandenberg & Kuse, 1978) to assess actual spatial abilities. I have used this test for several studies (Cherney et al., 2003, Cherney & Neff, 2004, Cherney & Collaer, 2005, Cherney & Rendell, submitted) and it is the most widely used test to study mental rotation (Halpern, 2000).

**Procedures**

Participants will complete the translated surveys and MRT during school with an experimenter present in the classroom to answer questions and for debriefing.

**Data Analyses**

The data will be coded and entered into SPSS (Statistical Package of the Social Sciences). Structural Equation Modeling, independent t-tests, analyses of variance (ANOVA), analyses of covariance (ANCOVA) and regression analyses will be used to identify the cultural differences and to understand the possible factors leading women to choose different careers.

**Schedule for completing the project**

<table>
<thead>
<tr>
<th>Items</th>
<th>Date of completion</th>
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<tbody>
<tr>
<td>Translation of survey questions</td>
<td>Jan-Feb 2008</td>
</tr>
<tr>
<td>Learning of SEM (Structural Equation Modeling – course in Omaha)</td>
<td>Jan 2008</td>
</tr>
<tr>
<td>Contact with Swiss schools</td>
<td>Jan-Mar 2008</td>
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<tr>
<td>Pilot testing of survey</td>
<td>Apr-May 2008</td>
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<tr>
<td>Data collection</td>
<td>May-Jun 2008</td>
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<tr>
<td>Data scoring</td>
<td>May-Jun 2008</td>
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<tr>
<td>Data entering/analyses</td>
<td>Jun-Jul 2008</td>
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<tr>
<td>Write-up for publication</td>
<td>Aug-Sep 2008</td>
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<tr>
<td>Conference submission</td>
<td>August 2008</td>
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<tr>
<td>Publication submission</td>
<td>September 2008</td>
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**Future Plans**

I will pursue external funding for this type of research. In particular, together with my Swiss collaborators (University of Bern), I plan to submit grant proposals to the Swiss National Science Foundation and to the appropriate commission of the European Union. In the US, I will be submitting a proposal to the National Science Foundation: Research on Gender in Science and Engineering (NSF 07-578). NSF created this special grant line with regards to the national competitive initiative. Getting this pilot grant will greatly increase the chances of being funded over many years.

Several undergraduate students will be working with the project, particularly during data entry, coding, and analysis. Aspects of the study will be presented at various national and international conferences (conferences of the Association of Psychological Science, Society for Research in Child Development, Society for Research in Adolescence, Cognitive Development Society, etc.). There are several peer-reviewed journals that can be considered as an outlet for this type of research. For example, the Journal of Adolescence, Cross-Cultural Psychology Bulletin, Current Directions in Psychological Science, The Journal of Cross-Cultural Psychology, The Journal of Experimental Psychology: General, The Journal of Social and Personality Psychology, Psychology of Women Quarterly, to name a few.
VI. References


Cherney, I. D., & Rendell (under revision). *Bridging the gender gap: Effects of testing medium and question type on visuospatial sex differences*


Appendices

Biographical Sketch: Isabelle D. Cherney, Associate Professor of Psychology

Education
Creighton University, Omaha, NE  Psychology (GPA 4.0)  B.A.  1996
University of Nebraska, Omaha, NE  Developmental Psychology (GPA 4.0)  M.A.  1999
University of Nebraska, Lincoln, NE  Educational Psych. & Cultural Studies  Ph.D.  2001

Selected Peer Reviewed Publications:
Summary of other activities:

- I was awarded several small national (e.g., American Psychological Foundation and Council of Undergraduate Research) and regional grants (Nebraska NSF EPSCoR, Creighton University) to conduct research on the development of cognitive sex differences. So far, I have been awarded 26 grants for a total of $50,000.00.
- 20 undergraduate students are co-authors on my publications
- 82 national and international conference presentations
- Reviewer for the National Science Foundation CCLI-AI
- Reviewer for 17 different journals/publishing companies
- 30 invited talks – several of these talks were on the development of cognitive sex differences and reasons for the under-representation of women in the sciences
- 10 students received competitive national and regional Summer Research Fellowships
- 85 students presented their research at regional and national conferences for a total of
- 52 sponsored student conference presentations
- Supervised 39 undergraduate students in independent study and research (in addition to standard teaching load)
- 2007 Carnegie Foundation for Advancement of Teaching Nebraska Professor of the Year
- The U.S. Professors of the Year program salutes the most outstanding undergraduate instructors in the country—those who excel in teaching and positively influence the lives and careers of students. Sponsored by CASE and The Carnegie Foundation for the Advancement of Teaching, it is the only national program to recognize excellence in undergraduate teaching and mentoring.
- 6 teaching-related grants
- Winner or finalist of 6 Teaching Award
- Acting Director of the Honors Program 2006-2007
- I was raised in Switzerland and fluently speak French, German, English, and Spanish
- Winner of Creighton University’s Academic Computing and E-learning Competition
- Maintain 3 websites
<table>
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<tr>
<td>Copies of surveys</td>
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<tr>
<td>Transportation in Switzerland (monthly train pass = 350.00 francs)</td>
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<td>SPSS License (statistical package) for laptop used in Switzerland</td>
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