

Motivation or cognition: What leads to performance
differences in science?

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Abstract

The present study investigated whether motivation is a more important factor than gender in determining performance differences in science. Additionally, cognitive differences in processing skills among males and females that might lead to performance differences in different content areas in science were assessed. The data set analyzed were obtained from the School Achievement Indicators Program (SAIP). Two random sub-samples of 352 English speaking students (age = 13 years) with full-time participation status from a population of 704 students were used. The analysis of the structural model was completed using LISREL 8. Results indicated that motivation is a more important predictor of science achievement than gender. The results also indicate that cognitive processing differences between males and females did not lead to performance differences in different content areas in science. The results are important in that they suggest that in addition to examining differences from a psychological perspective there is a need to look into a social perspective as a potential cause for differential performance in science.

Theoretical Framework

There is a substantial body of research that documents gender differences in science and shows that males outperform females on science achievement tests (Chipman, Brush & Wilson, 1985; Fennema, 1984; Linn & Hyde, 1989; Oakes, 1990; Lee & Burkam, 1996). For example, in Canada, the provincial assessment of science in 1995 in British Columbia revealed that males outperformed females in several science topics such as physics, electricity, mechanics and space sciences whereas females outperformed males in science topics such as biology and earth sciences (Bateson et al., 1986b; Hobbs, Boldt, Erickson, Quelch, & Sieben, 1979; Taylor, Hunt, Sheppy, & Stronck, 1982). A major impediment in explaining why these differences in performance occur arises because there appears to be multiple causes of differential performance. For example, cognitive differences between males and females, such as mathematical, spatial, or verbal skill, may result in performance differences on certain test items (Ibarra & Cohen, 1997; Williams, Waldauer, & Duggal, 1992; Anderson, Benjamin, & Fuss, 1994; Hirschfeld, Moore, and Brown, 1995). From a sociological perspective, differences in performance might be the result of different “out-of-school” experiences of males and females. Such differences in experiences and activities might in turn lead to differences in motivation to seek knowledge about science, which in turn will lead to performance differences in different content areas in science (Bateson & Parsons-Chatman, 1989).

Researchers who have focussed on attempts to explain gender differences in science have generally taken two theoretical perspectives: cognitive and sociological. The cognitive perspective deals with the manner in which information is acquired and

processed (sequential or parallel processing, field independence/dependence, memorization skills, and spatial visualization).

Cognitive/Psychological perspective: Much research on cognitive gender differences in science is inconclusive and conflicting. In 1974, Maccoby and Jacklin, in a landmark analysis, concluded that gender differences existed for verbal ability and spatial ability. According to Haggerty (1987) females who are socialized towards using rote learning strategies do substantially better in life sciences such as biology rather than physical sciences such as physics and chemistry. She suggested that this difference was attributable to the heavy demand for higher level processing skills in chemistry and physics than in biology.

Linn and Hyde (1989) concluded, on the basis of their synthesis of research on gender differences in science that differences in verbal ability is diminishing. Their process analysis revealed that females outperformed males where the verbal content was about aesthetics but the reverse was true when the verbal content was about practical affairs. Furthermore, Linn and Hyde (1989) suggested that inferior performance by females compared to males on tests such as the Scholastic Aptitude Test (SAT) could be attributed to females disadvantage in speed. For example, the observation that males outperform females on this test may be attributable to the fact that the process required for earning very high scores on this test includes the ability to solve problems quickly and high scores by males as compared to females seem to suggest that males may have an advantage with speed.

According to Linn and Hyde (1989) gender differences in spatial ability are declining. However, Halpern (1997) reports that men, on average, excel at tasks that

require the retention and manipulation of visual mental representations in working memory. These tasks include mental rotation and spatial perception tasks. Casey, Nuttall, Pezaris, and Benbow (1995) and Casey, Nuttall, and Pezaris (1997) found similar results. They found mental rotation to be a critical mediator of gender differences for specific sub-tests on the SAT, specifically for the high ability male examinees.

Sociological perspective: Such lack of consensus regarding cognitive gender differences has led researchers to delve into other potential causes for differences in performance among males and females in science. Of them the more important and widely accepted ones in the educational community are those that offer a sociological perspective (motivation and experience). For example, Linn and Hyde (1989) in their review of gender and science concluded that informal as well as formal learning experiences were important determinants for gender differences in science. Erickson and Farkas (1987) suggested that males and females draw on different sources of knowledge when confronted with a test question and that lack of prior informal experiences contributes to females' inferior performance in applied areas of science such as physics chemistry, mechanics and electricity. However, the superior performance of females in biology and earth science is attributed to their familiarity in using rote memorization and learning skills. A further conjecture advanced by Johnson and Murphy (1984) is that societal expectations for men and women result in different kinds of expectations in the early socialization of boys and girls that are reinforced by appropriate role models from real life in the media and in textbooks. The role models used emphasize that males and females are involved in different leisure time activities. Johnson and Murphy suggested that such activities might also lead males and females to greater motivation to perform

better in different subject areas. According to Adelman and Taylor (1986) and Gottfried (1983, 1985), motivation is an extremely important factor for determining academic success. Motivation can be intrinsic or extrinsic. Intrinsic motivation is referred to as participation in an activity purely out of curiosity and extrinsic motivation is referred to as participation in an activity purely for the sake of attaining a reward or for avoiding punishment (Woolfolk, 1990). Numerous research studies suggest that intrinsic motivation or, more specifically, academic intrinsic motivation is the key factor to higher academic achievement (Gottfried, 1983; Schunk, 1990). The intrinsically motivated student is more likely to retain the concepts learned and to feel confident about dealing with unfamiliar learning situations than the extrinsically motivated student is.

Consequently the questions addressed in the present study were:

1. Is motivation more important than gender in determining performance differences in science?
2. Are differences in cognitive processing skills between males and females a key factor that determines performance differences in different content areas in science?

Method

Data

The study was conducted using existing science test data obtained from the School Achievement Indicators Program (SAIP) conducted in 1996. SAIP was initiated by the Council of Ministers of Education, Canada (CMEC) to provide a mechanism for reporting on levels of achievement attained by 13- and 16-year old students across

Canada. The study used two random sub samples of 352 English speaking students (age = 13 years) with full-time participation status from a population of 704 students.

Variables

Items on the SAIP science test were categorized into physics, chemistry, biology, and earth science items. This was done using content blueprints and expert judgement. The variable motivation was obtained by combining four items taken from a set of fifty-eight background questions. These 4 items measured various aspects of motivation such as hard work, interest in science and desire to attend science exhibitions and fairs. The internal consistency of the subset of motivation items was 0.71.

Analytical Procedure

If the assumption is that male and females differ on cognitive skills such as verbal, memorization, and visual-spatial skills then this difference should affect their performance in different content areas in science. For example, physics and chemistry require more visual-spatial and higher-level problem solving skills than biology. Therefore males should do better in physics and chemistry. Whereas females should do better in biology and earth sciences, which require more memorization and verbal skills. This assumption is reflected in the structural model presented in Figure 1 and that was tested using LISREL 8 (Jöreskog and Sörbom, 1996). The unidirectional arrows from gender (exogenous variable) to physics, chemistry, biology, and earth science (endogenous variables) reflects the hypothesis that gender affects all the content areas in science. More specifically, the purpose is to demonstrate that males outperform females in physics and chemistry and females outperform males in biology and earth science. Likewise, the unidirectional arrows from motivation to physics, chemistry, biology, and

earth science reflects that gender affects science achievement through motivation, which acts as a mediating variable (see Johnson & Murphy, 1984; Bateson & Parsons-Chatman, 1989).

The fit of the variance-covariance matrix of the observed data to the variance-covariance matrix calculated from the model was tested using five fit statistics. The chi-square was used because it is widely accepted as a measure of model data fit. However, the chi-square is sensitive to conceptually unrelated technical conditions like sample size (Bandalos, 1993; Boomsma, 1987) or a violation of the multivariate normality assumption (Curran, West, & Finch, 1996; Hu, Bentler, & Kano, 1992; West, Finch, & Curran, 1995). Hence, four additional fit indices were used: Adjusted Goodness of Fit Index (AGFI), Root Mean Square Error of Approximation (RMSEA), Non-Normed Fit Index (NNFI), and Comparative Fit Index (CFI). In the present study Hu and Bentler's (1999) criteria for assessing model fit were adopted: a value of 0.95 or greater for AGFI, 0.06 or lower for RMSEA, 0.90 or greater for NNFI, and 0.95 or higher for CFI.

The standardized residuals (fitted residual divided by the large sample standard error of the residual) were also examined. The standardized residuals were examined instead of the fitted residuals because the standardized residuals are independent of the units of measurement of the variables and provide a "statistical" metric for judging the size of the residual. A large positive residual for two variables indicates that the model underestimates the covariance between the two variables while a large negative residual indicates that the model overestimates the covariance between the two variables. Standardized residuals that are greater than an absolute value of 2 are considered large (Hayduk, 2002). The standardized residuals were also examined collectively in a Q-plot.

Points falling approximately on a straight line characterize a good model. Deviations from this pattern are indicative of specification errors in the model, non-normality of the variables, or non-linear relationship among the variables (Jöreskog and Sörbom, 1996).

The gamma and beta coefficients were examined to see whether motivation was a more important than gender in determining science achievement. Positive and significant gamma coefficients from gender to different content areas in science indicate that males outperform females in those content areas. However, negative and significant gamma coefficients from gender to different content areas in science indicate that females outperform males in those content areas.

The results obtained in the first analysis were replicated using the second random sub-sample of 352 students.

Results and Discussion

The results of the first analysis (sub-sample 1) are reported in the first panel in Table 1. The chi-square value was not statistically significant ($\chi^2 = 12.39$, $df = 6$, $p > 0.01$) suggesting good model-data fit. The remaining fit indices, AGFI, RMSEA, NNFI, and CFI also indicated good fit. Furthermore, a large proportion of standardized residuals were less than an absolute value of 2 and fell approximately on a 45-degree line in the Q-plot.

The results of the replicated analysis (sub-sample 2) are reported in the second panel in Table 1. Again the chi-square value was not statistically significant ($\chi^2 = 15.87$, $df = 6$, $p > 0.01$) suggesting a good model-data fit. With one exception the other fit indices also indicated good fit. The RMSEA was slightly larger than 0.06 indicating a

small misfit. As with the first sample, a large proportion of standardized residuals were less than an absolute value of 2 and also fell along the 45-degree line in the Q-plot.

Based on the values of the fit indices, we concluded that the model shown in Figure 1 fit the data well for both random sub-samples.

As shown in the first panel in Table 2, the beta coefficients for the first analysis are large and statistically significant ($p < 0.05$) while the gamma coefficients are small and statistically insignificant ($p > 0.05$). This suggests that motivation contributed to science achievement much more than gender for all four science content areas. For example, for each unit change in motivation, there is a 6.055 unit change in biology. However, for each unit change in gender there is only 0.758 unit change in biology. As shown in the second panel in Table 2 this trend is similar for all the content areas in science. However, inconsistent to previous research, gamma coefficients from gender to all the content area in science are not statistically significant. Therefore, we cannot conclude whether males outperform females in physics and chemistry and females outperform males in biology and earth science.

Similarly, as shown in the second panel in Table 2, the results for the second analysis also suggest that motivation contributed to science achievement much more than gender in each content area in science. However, the results do not indicate which content areas favor males or females.

Conclusions and educational contribution

The findings of the present study support the hypothesis that motivation is a more important predictor of science achievement than gender. However, the findings do not support previous research that males outperform females in physics and chemistry and

females outperform males in biology and earth science. The failure to show that males outperform females in physics and chemistry and females outperform males in biology and earth science might be attributed to the fact that each content area in science requires, in addition to visual-spatial, higher level thinking, memorization, or verbal skills, other cognitive skills that are not gender specific. Another point to be noted is that the content areas are only as good as the blueprints used to be. For example, under-representation or over-representation of the content may occur by the number and types of items included in each content area (Messick, 1989). These important, yet probably unidentified factors can lead to invalid results. Hence, the study warrants further investigation into the different content areas for identifying under- or over-representation of content. The results of the present study are important in that they suggest that in addition to examining differences from a psychological perspective there is a need to look into a social perspective as a potential cause for differential performance in science.

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Table 1

Fit indices for the structural model

	χ^2 (df)	P-value	AGFI	RMSEA	CFI	NNFI
Sub-sample 1	12.39 (6)	0.053	0.962	0.055	0.981	0.953
Sub-sample 2	15.88 (6)	0.014	0.952	0.068	0.970	0.926

Table 2

Gamma and Beta coefficients

Sub-sample 1	Gender (Gamma)	Motivation (Beta)
Biology	-0.758	6.055 *
Earth-Sciences	-0.925	7.718 *
Chemistry	-0.343	3.364 *
Physics	-0.769	8.052 *
Sub-sample 2	Gender (Gamma)	Motivation (Beta)
Biology	-0.251	8.382 *
Earth-Sciences	-0.140	9.177 *
Chemistry	0.093	4.301 *
Physics	-0.184	8.248 *

* $p < 0.05$

Figure Caption

Figure 1. Structural model to show the effect of gender and motivation on different content areas in science.

