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ABSTRACT

This study is second in a series demonstrating that achievement tests are multidimensional and that using psychologically meaningful subscores in national educational surveys can enhance test validity and usefulness. National Education Longitudinal Study 1988 (NELS:88) 8th- and 10th-grade science tests were subjected to full information item factor analysis. Factors reflecting everyday knowledge, scientific reasoning, chemistry knowledge, and reasoning with knowledge were obtained in 8th grade. Quantitative science, spatial-mechanical, and basic knowledge and reasoning were distinguishable factors in 10th grade. Regression analyses showed that different patterns of prior math and science achievement, and of course taking, were associated with each 10th-grade science factor. Teacher emphasis on problem solving and understanding related more to quantitative science and basic knowledge and reasoning. Spatial-mechanical reasoning showed the strongest gender and ethnicity effects; it related also to science museum visits, but not to instructional variables. It is recommended that multidimensional achievement scores be used to capture student and teacher effects that total scores alone miss. Nine tables illustrate the analysis. (Contains 5 references.) (SLD)

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II. NELS:88 Science Achievement

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The work reported here was a team effort; the authors share equally in the responsibility for the research and its conclusions. Requests for reprints should be sent to Professor Richard E. Snow, School of Education, Stanford University, Stanford, CA 94305.

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Abstract

This study is second in a series demonstrating that achievement tests are multidimensional and that using psychologically meaningful subscores in national educational surveys can enhance test validity and usefulness. NELS:88 8th and 10th grade science tests were subjected to full information item factor analysis. Factors reflecting everyday knowledge, scientific reasoning, chemistry knowledge, and reasoning with knowledge were obtained in 8th grade. Quantitative science, spatial-mechanical, and basic knowledge and reasoning were distinguishable factors in 10th grade. Regression analyses showed that different patterns of prior math and science achievement, and of course taking, were associated with each 10th grade science factor. Teacher emphasis on problem solving and understanding related more to quantitative science, and basic knowledge and reasoning. Spatial-mechanical reasoning showed the strongest gender and ethnicity effects; it related also to science museum visits, but not to instructional variables. It is recommended that multidimensional achievement scores be used to capture student and teacher effects that total scores used alone miss.

Enhancing the Validity and Usefulness of Large-Scale Educational Assessments II. NELS:88 Science Achievement

This study is the second in a series designed to examine the construct validity of mathematics and science achievement tests used in national survey research on school and teaching practices. The primary purpose was to determine if psychologically meaningful subscores could be distinguished within these tests to show differential relationships with educational survey variables. If this can be done, then achievement constructs might be elaborated and the usefulness of survey analyses for informing educational theory, policy, and practice might be significantly enhanced.

Background

In a previous report, the NELS:88 mathematics tests for 8th and 10th graders were analyzed into separate subscores. Regression models were constructed for each subscore, as well as for the total IRT scores available from the NELS:88 public use data tape. The results suggested that further research aimed at theory or policy should use at least two separate dimensions, labeled "knowledge" and "reasoning" for short, rather than a solitary total score, to represent math achievement (see Kupermintz, Ennis, Hamilton, Talbert, & Snow, submitted). The two dimensions, though correlated, clearly differed psychologically, as shown in their relations to various other student, instructional, and school variables. Analyses relying on total scores alone misrepresented some important effects and missed others altogether. For example, total score analyses failed to show gender effects that appeared on math reasoning but not on math knowledge. Effects of SES and ethnicity were also misrepresented. In general, course taking, school program, and instructional practice variables showed stronger relations to knowledge than to reasoning; total score analyses often appeared to average the two kinds of effects. Thus, studies of student readiness and opportunity to learn, and evaluations of school and teaching practices, could profit significantly by distinguishing these different facets of cognitive development in mathematics. Perhaps, new assessment designs could be made to separate these facets explicitly.

The present report considers the same issue for survey research on science achievement with specific reference to the NELS:88 8th and 10th grade science tests. Our ultimate goal is to define psychologically distinguishable dimensions of performance in both math and science across grade levels and, perhaps, one or more multivariate growth models for student ability development across the high school years.

However, we can predict that the domains of math and science may be quite different in this regard. In math, there is often a tight sequence of prerequisite relations between courses. This sequential-hierarchical structure of courses and instruction in them might be expected to produce relatively high correlations between the test items and tasks in different parts of the domain, both within and between grades. These correlations could then be accounted for by similar, and rather few, dimensions of performance at each grade level. This is precisely what our NELS:88 math study found. We could thus standardize the knowledge and reasoning dimensions to provide a common scale for each across grades. The implied multivariate growth model might then be extendable to later points in time.

In science, at least typically, there is no comparable structure to knowledge and skill acquisition across courses or grades. Courses may be taken in different sequences. Each science domain is likely to be taught without significant reliance on, or even reference to, the others. Cumulative science achievement may thus be compartmentalized and patchy, even scattered. Many small components or dimensions may appear and these may be qualitatively different at different grade levels. A very different model of growth might be needed. Of course, different test designs could result in more apparent homogeneity or heterogeneity in either math or science domains; different curricula, instructional designs, and teaching practices could also change these trends radically.

Our present analyses were geared to examine different structures for each domain. Also, given that our project has not yet accessed the 12th grade data, we recognized that any model of growth thought useful in either domain at this stage would be quite tentative, until the complete longitudinal data set is available. At least, our regression analyses of subscores for 8th and 10th grade achievement could provide important directions for the full longitudinal analysis.

Method

Our previous report described the NELS:88 survey and test design and provided a rationale for our project's methodological approach. In brief overview, the NELS:88 base year data consisted of math and science as well as history and reading test scores obtained from 24,600 8th graders from 1052 schools across the U.S. Extensive questionnaire responses were also obtained from the students and their parents, the school, and two of each student's teachers. Follow-up questionnaires and tests were collected when the students reached 10th grade and again in 12th grade.

As with the math test analysis, intercorrelations among science test items were subjected to several kinds of principal component and factor analysis, and to nonmetric multidimensional scaling, using the NELS:88 8th and 10th grade data. Small-scale interview studies were also conducted on the test and questionnaire items using local 8th and 10th grade student volunteers. Subscores for the science tests identified in these ways were then included in regression analyses using other student, course, program, and instructional practice variables as predictors. (See Ennis, Kerkhoven, & Snow 1993, and Kupermintz, et al., submitted, for details.)

The NELS:88 science tests. The science test consisted of 25 multiple choice items at 8th grade; 7 of these were dropped and replaced at 10th grade. Unlike the math test, no proficiency levels were specified in the science test, and separate forms were not created for different levels of the 10th grade distribution. Science item descriptions and master item numbers used in our analyses are given in Table 1.

Table 1 here

Samples. Preliminary analyses of the science items began with those 8th graders whose data file included reports from both a science and an English teacher. This sample included 5014 cases. Later analyses of both 8th and 10th grade data required only that a science teacher report was included, but at both grades. This sample included 5041 cases. As with the study of NELS:88 math achievement, some science test analyses used random subsamples for cross-validation purposes. Only combined results are reported in the present paper. The 50 local high school students used for small-scale interview studies of the math items also provided data for the science items.

Scoring. Science items were scored simply as right or wrong. Again, the IRT total score for Reading served as a measure of general verbal ability.

Questionnaire measures were scored as specified elsewhere in this and the previous report.

Analysis and Results

Dimensional analysis. Again, exploratory dimensional analysis of the 8th grade data used principal component and factor analysis, nonmetric multidimensional scaling, and codes obtained from student interviews. Different methods seemed to agree. A principal component solution yielded four components with eigenvalues greater than unity. The Stout (1987) test confirmed the multidimensional nature of the science test. Varimax rotation suggested interpretations that distinguished everyday or elementary science knowledge from more school-based and advanced, formal science achievement, identified a few items that seemed to measure mostly reasoning, and grouped a few other items as a kind of difficulty factor. The nonmetric multidimensional scaling analysis seemed to allow a further subdivision of the everyday knowledge items and the formal school science items into subgroups. Everyday knowledge was divided into items with and without reasoning demands. Formal achievement was divided into items reflecting basic versus advanced knowledge and reasoning. Interview results seemed to support these distinctions. The full set of preliminary subscales are identified in the upper panel of Table 2. Details of analysis and interpretation are available from Ennis, Kerkhoven, and Snow (1993).

Table 2 here

Similar exploratory analyses were also conducted on the 10th grade science items. However, as with the math analysis, the 8th grade and 10th grade science test items were also submitted to full-information factor analysis (Bock, Gibbons, & Muraki, 1988; Wilson, Woods, & Gibbons, 1991); this procedure seemed to provide the most statistically justifable results. A four-factor solution was chosen for the 8th grade, and a three-factor solution was chosen for the 10th grade, because these solutions appeared the most interpretable, and also met Chi-squared statistical criteria. For 8th grade science, the change in Chi-squared statistics for the fitted models indicated significant results for adding a second (Chi-squared change = 324.74, df = 24), a third (Chi-squared change = 44.06, df = 23), and a fourth factor (Chi-squared change= 169.08, df = 22). For 10th grade, the change in Chi-squared statistics for the fitted models indicated significant results for adding a second (Chi-squared change = 235.47, df = 24) and a third factor (Chi-squared change = 70.59, df = 23).

The lower panels of Table 2 give the 8th and 10th grade science factors thus identified. Table 3 presents the promax rotated factor loadings for each item by factor at each grade level.

Table 3 here

For 8th grade science, although items clustered to some extent on the basis of subject matter, clear distinctions between science domains did not routinely appear in either the component analysis or the full information factor analysis. The level and kind of reasoning required did distinguish among some dimensions; some items seemed to demand scientific reasoning, or its application with knowledge, whereas others called mainly for knowledge of specific terms or concepts. In addition, formal, school-based knowledge seemed to be distinguished from more informal everyday knowledge that can be acquired outside of school. Although these distinctions appeared in both the principal component and the full information factor analysis, the latter solution seemed clearest, so we have emphasized that in our discussion. The labels for the factors represent our attempts to characterize the items according to these features.

The first factor, called "scientific reasoning (SR)", contained five items requiring manipulation of numerical equations, interpretation of graphs, or hypothesis formulation. For example, one item described a geological finding asking the student to identify a possible explanation. There was also an item that asked the student to select a procedure that would improve upon an experimental design. Some of the items involved the application of knowledge of science vocabulary terms, such as "potential energy" or "moles," but the primary feature that characterized these items seemed to be their reasoning requirement. This factor included the items classed as S1b and most SC4 items from the preliminary component analysis.

Four items loaded strongly on the second factor, "chemistry knowledge (CK)". Unlike the other factors, this one seemed to be defined primarily by subject matter. These items included concepts such as mixtures and compounds, chemical change, and solubility. They required knowledge of chemistry terms, but placed few reasoning demands on students. Their content, like that of the items on the first factor, appeared to reflect formal, school-based science. These items, however, involved less advanced material than some of the chemistry items that loaded on other factors; for example, a chemical equation problem loaded mainly on SR. This factor included SC2 items from the component analysis.

The twelve items that loaded strongly on the third factor, "everyday or elementary science (ES)," required knowledge of scientific concepts that could easily be learned outside of school. These items, therefore, may have placed fewer demands on students' school-acquired knowledge and understanding by addressing a broader range of elementary science learning experiences. All five astronomy items loaded on this factor, and most of these involved elementary knowledge about the solar system. Other items required students to identify concepts such as a simple reflex, or plants as the source of oxygen in the oceans. Although students may acquire their knowledge about science from various sources, it is likely that these particular items reflected more everyday knowledge than items loading on the other three factors. This factor included most S1a and some S1b and SC2 items from the component analysis.

The four items with strong loadings on the fourth factor, "reasoning with knowledge (RK)", involved formal scientific concepts as well as the requirement to apply reasoning skills. These concepts included photosynthesis, barometric pressure, and the movement of cool and warm air. They differed from items on the first factor primarily in the sense that the concepts here were less advanced and somewhat less specific. In addition, in these items, the formal scientific terms appeared in the response options rather than in the stems; this might have placed less demand on science vocabulary knowledge.

Our analysis of the 10th grade science items identified three factors which we term "quantitative science" (QS), "spatial-mechanical reasoning" (SM) and "basic knowledge and reasoning" (BKR). These factors appeared to represent qualitatively distinct types of science achievement, different in several respects from those identified at the 8th grade level.

The quantitative science factor (QS) contained twelve items related to areas of science that are predominantly quantitative in nature. Many of the items required students to perform mathematical operations such as calculating a mass or interpreting graphs. Two-thirds of the items concerned chemistry, and included those defining the chemistry knowledge factor from the 8th grade. Although some of the chemistry-related items were not quantitative, they required knowing facts about chemical changes, an area of science that is heavily quantitative. This factor also contained some 8th grade SR items, so it was partially a combination of the 8th grade SR and CK factors.

The spatial-mechanical reasoning factor (SM) contained five items, most of which involved interpreting diagrams or reasoning about physical systems. For example, two items asked questions about pictured physical devices. Another asked students to interpret a map. These three, the strongest items on this factor, were new to the test at 10th grade.

The basic knowledge and reasoning factor (BKR), contained eight items assessing knowledge of scientific concepts, and in some cases the ability to apply these concepts to simple reasoning situations. Five of the seven items related to biology; one item related to astronomy and one to physics. Several 8th grade ES and some SR and RK items appeared here. Indeed, the items at the core of this factor were those that also defined ES at 8th grade. The factor appeared to combine ES and RK. In addition, many of its items took the form "which of the following is true (or) ...is an example of...", suggesting that the factor reflected elementary science explanation.

Again, the small-scale interview study both aided factor interpretation and helped identify several items in which the knowledge and reasoning that led students to correct answers seemed quite different from what item writers must have intended. In two cases, the majority of correct answers in our interview study came from misunderstandings about item content. Some items also seemed to allow nonsubstantive or impulsive responses to reach correct answers while possibly confusing more knowledgeable or reflective students with apparent complexities. Apparently items can have properties that are central to their functioning in the test but that elude the content experts who judge them. This does not necessarily invalidate these items, but it does imply that expert judgment is not a sufficient condition for test validation. More detailed discussion of these problems, with examples, is provided by Ennis, Kerkhoven, and Snow (1993). Although we chose not to delete any of these items from the large-scale science test analyses, it is possible that the complexity of some component and factor results, particularly at the 8th grade level, may have arisen partly from this source.

Relation to test specifications. Table 4 shows the original test specification table for the 8th grade science test, to which we have added our factor designations from the 8th grade analysis. As with math, we do not yet have access to the 10th grade test specification table.

Table 4 here

Note that some factors correspond to regions of the table. Earth and life science knowledge is largely represented by the ES or everyday elementary science factor. Items defining the CK factor appear in the chemistry column. However, most cells in the table contain items from more than one factor; the comprehension and problem solving rows are particularly mixed. This is another demonstration that test specification tables may be of help in item writing and selection, but they should not be retained as construct definitions because they are unlikely to represent the psychological nature of item-level performance.

Student, course, program, and instructional variables. Four regression models were specified for each 10th-grade science factor. The four sets of variables included student characteristics, course-taking and program participation, instructional practices, and outside opportunities to learn. A final model then included all variables that had made significant contributions in the first four models.

All models included student prior achievement variables as controls. These were the four 8th-grade science factors, 8th grade reading IRT score, and the two 8th grade mathematics factors representing math knowledge and reasoning. The math factors were derived from our previous work (see Kupermintz, et al., submitted).

In addition to prior achievement variables, the first model included student background variables, specifically frequency of absenteeism (reported by teacher), gender, socioeconomic status, and ethnicity (indicator variables for Asian, Black, and Hispanic). Variables representing attitudes toward science and math (Science Att 8 and Math Att 8) were constructed by combining student responses to two items: extent to which science or math is important in the student's future, and extent to which the student looks forward to science or math class. Four affective variables were also included: level of anxiety related to math (Math Anx), emphasis on luck versus hard work as a source of success (Luck 8), and two self-esteem factors (Pos Self 8 and Neg Self 8). The last three were obtained by factor analysis of NELS:88 8th grade student questionnaire items not included here.

The second regression model included course variables, reflecting only whether or not the student had ever taken particular courses. Dummy variables also indicated high school program (advanced versus academic versus general-vocational) as reported by teachers, and participation in gifted and talented programs, as reported by parents. A final variable indicated whether or not the student had taken algebra in the 8th grade, which might be an important early opportunity to learn advanced mathematics.

The third regression model included instructional variables. Most of these variables resulted from a factor analysis of teacher questionnaire items (not reported here). Some factors were eliminated from the regression analysis because they were partially redundant with others. Table 5 shows the factors included in the regression models, along with their corresponding items. In addition to these factor scores, several individual items were used as variables, including teacher emphasis on facts, emphasis on problem solving, and reports of time spent on homework and whether homework was discussed in class. Finally, student responses to the question, "How often are you asked to show that you really understand the material, rather than just give an answer?" were added. Although the reliability of such student reports is unclear, this item was included as a proxy for teaching for understanding because no comparable question appeared on the teacher questionnaire. We also reviewed other student questionnaire items relevant to instructional practices, but none appeared from our preliminary analysis to be useful predictors.

Table 5 here

An important aspect of students' science learning is the experience they gain outside of school. Hence a fourth regression model was constructed to investigate the effects of six outside opportunity-to-learn variables: visits to science museums, parental help with homework, access to a computer in the home for educational purposes, participation in a computer class outside of school, participation in science clubs, and hours of television watched per day. The first four were reported by parents, the last two by students. Unfortunately, the student questionnaire did not distinguish TV viewing of science and nature programs from other forms of TV viewing.

Regression analysis for main effects. The results for all regression models using standardized variables are presented in Tables 6 through 9. Table 6 shows results for QS; all prior achievement variables were significant predictors of 10th grade achievement on the quantitative science factor. The strongest predictor was math reasoning, followed by math knowledge and reading ability. Of the 8th-grade science factors, "chemistry knowledge" and "reasoning with knowledge" were the more important of the science achievement predictors. These results are consistent with an interpretation of this factor as characterized by quantitative reasoning and knowledge of chemistry. Other significant student predictors were gender (favoring males), socioeconomic status, attitude toward science, and absenteeism.

Table 6 here

Performance on the quantitative science factor was positively related to having taken chemistry and physical science. The coefficient for chemistry was the second largest in this model, following student prior math reasoning.

Although no effect of instructional variables on science factors was strong, quantitative science showed several significant relationships, probably because QS achievement requires more of the advanced scientific operations acquired in high school courses than do the other factors. Teacher emphasis on understanding and problem solving, and the frequency with which experiments were conducted in class, were significant positive predictors. Teacher use of film and audiovisual materials was a significant negative predictor.

The regression analysis for outside opportunities revealed two significant positive effects on quantitative science: presence of a computer in the home for educational purposes, and visits to science museums. The effect of socioeconomic status observed in the student model may also result, at least in part, from exposure to science educational opportunities more commonly available in middle and upper class families.

Table 7 here

Predictors of performance on the spatial-mechanical reasoning factor are shown in Table 7. Significant student variables included all 8th-grade science factors except "scientific reasoning," which had negative weight. Reading showed significant but relatively weak relation. Math knowledge was not significant, but math reasoning and the science factor labeled "elementary science" were the strongest predictors. These results are consistent with the interpretation of the SM factor as dependent on spatial relations and visualization abilities. Spatial abilities are rarely addressed in formal instruction, though they may be promoted by some activities in shop or mechanical drawing classes; they do seem to play a role important in science. Math reasoning and spatial mechanical reasoning are also often found related, and students strong in such abilities may more readily pick up related everyday science knowledge. Factor SR, formal scientific reasoning, on the other hand, is taught explicitly in school; it might thus be expected to show low relation to SM. But its regression weight should not be negative given positive zero-order correlations; apparently, SR served as a suppressor variable here, removing non-SM-related variance in other predictors.

The strongest predictor of spatial-mechanical reasoning was gender. According to our models, the male score average was nearly one-half standard deviation higher than the female average. The coefficient for gender on SM was much larger than the gender coefficient for other factors, though it was significant for QS, and also for mathematical reasoning (see Kupermintz, et al., submitted). Note also that reading achievement was a significant predictor only when gender was in the model; removing gender reduced the coefficient for reading to zero. This finding may result in part from the correlation between gender and reading, favoring females, and from the large gender effect favoring males on the spatial-mechanical factor. Unless gender is included in the model, the positive effect of reading is suppressed by the fact that a higher proportion of more able readers are females, who tend to do worse on average (for other reasons) on spatial-mechanical tasks.

Performance was also related to socioeconomic status and to some ethnic indicators. Although the coefficient for the Asian indicator was not significant, there were significant negative coefficients for the Black and Hispanic indicators. As with gender, these relationships were larger on SM than those observed on the other two science factors. No affective or attitudinal variables were significant.

The only course that showed predictive power on the spatial-mechanical factor was earth science. Consistent with the hypothesis that spatial-mechanical reasoning is not emphasized in science classrooms, relative to other forms of reasoning, no significant effects for instructional predictors were obtained. Home computers and visits to science museums, however, did have significant relation to SM, with science museum visits showing an especially large effect. This may reflect a selection factor, wherein students already high in spatial ability visit science museums more frequently. On the other hand, the spatial-mechanical nature of many science museum exhibits may help students understand how physical systems operate, enhancing both comprehension and reasoning with spatial-mechanical concepts. Thus, although SM does not seem heavily influenced by conventional science classroom activities, our results for science museums may suggest an important way in which it can be promoted.

Table 8 here

Results for the basic knowledge and reasoning factor (BKR) are shown in Table 8. All achievement variables except 8th-grade chemistry knowledge were significant predictors. Absenteeism was also important, indicating that at least some of what is needed to perform well on this factor is probably acquired in school. The strongest predictor, however, was score on the 8th-grade factor representing elementary science (ES). ES and BKR share some of the same items, so they may be considered quite similar as factors. The next highest coefficient was for reading achievement. As with QS, performance on BKR was related to attitude toward science but not to any of the other affective or attitudinal variables. Socioeconomic status was also significant. There was a negative coefficient for the Black but not for the Asian or Hispanic indicators.

Taking biology was an important predictor of BKR. The only instructional predictors with significant coefficients on BKR reflected emphasis on problem solving and understanding. In contrast to the other two factors, performance on BKR did not appear to be related to any outside opportunity variables.

Table 9 here

Effects noted as significant in the partial analyses were brought together in summary regression models. As shown in Table 9, these models yielded patterns similar to those seen in the separate regressions of SM and BKR on the various categories of predictor variables. The exception was the summary model for QS. Here, prior experience with chemistry retained its high level of significance, but the effects of instruction and of outside opportunities to learn became non-significant. Apparently, instructional practices that contribute to performance on this dimension of achievement are confounded with the chemistry course variable. Students who have taken chemistry are more likely to have teachers who emphasize problem solving and incorporate experiments into their teaching, whereas they are less likely to have teachers who regularly use films in the classroom.

Effects on quantitative science achievement for computers in the home and visits to science museums were diminished with controls for students' socioeconomic status in the summary model. Although the effect of home computers on spatial-mechanical reasoning was also diminished by inclusion of SES, the effect of science museums remained strong. Thus, while apparent effects of out-of-school learning opportunities on quantitative science could be part of more general SES advantages, the effects of science museum attendance on spatial-mechanical reasoning appears to be independent of SES.

Finally, we computed a summary regression model to predict total math IRT score (see Table 9, far right column). Comparing the overall model for total science score with those for the separate factors shows several important results. As with the math analysis (see Kupermintz, et al., submitted), the science total score is seen to average and thus mask differential patterns of effect estimates across the 10th grade science achievement factors. Attending only to total score, the negative weight of 8th grade SR for 10th grade SM is missed. It is not seen that 8th grade CK is primarily a predictor of QS at 10th grade, not the other two factors, whereas 8th grade ES shows the opposite pattern. Also, the differential roles of 8th grade reading and math knowledge are missed. Perhaps most important among the student variables is the demonstration that spatial-mechanical reasoning is a separable dimension that may be a primary source of gender and ethnic differences in science achievement.

Two results from analysis of course and program variables deserve note. First, participation in general-education as opposed to academic programs had a significant negative effect on total IRT score, deriving mainly from the BKR factor; this effect was not significant for the QS or SM factors. Second, the strong and selective effects of particular courses disappeared, presumably because the total score does not distinguish among different areas of knowledge and understanding. Effects for instructional and outside learning variables concerned with teaching for problem solving and understanding, and the role of science museums, were also missed or distorted by the total score analysis. These findings provide strong support for our view that different components of achievement should be distinguished.

Discussion and Conclusions

Our results demonstrate the importance of identifying different forms of science knowledge, understanding, and reasoning, and of exploring various predictors as influences on these forms of science achievement whenever students are assessed or educational programs are evaluated. Although the achievement measures and survey instruments used in NELS:88 are limited in scope, they allow a number of important distinctions among predictor variables and among the dimensions of science achievement that can be used as criteria. Our analyses show that various student characteristics are important predictors of later achievement and indicate also that exposure to different courses and instructional practices affects achievement. However, these effects depend upon the kind of achievement being measured. Combining many different types of science items into a total score may obscure or distort important effects, and therefore our understanding and use of them.

In attempting to identify teacher practices that influence achievement, it is important to acknowledge the limitations of our data. Although we have identified several components of science knowledge and reasoning, the format of the achievement tests precludes measuring certain aspects of understanding and problem solving, or performance on laboratory activities. Also, the nature of the survey items administered to teachers limits the extent to which we can identify and represent important teacher practices. For example, the NELS:88 survey did not include questions about instructional practices that promote discovery learning or reciprocal teaching. Even with such items, one might doubt that responses to survey questionnaires could capture the subtle distinctions among teachers that render their instruction more or less effective. However, statistical analysis can reveal some of these distinctions among teaching practices that have a greater effect on some dimensions of student achievement than on others. That is an important step toward improved understanding of science teaching.

The results also underscore the importance of outside-of-school experiences and activities. The effects of home computers and visits to science museums seem especially important for some kinds of achievement development, e.g., spatial-mechanical reasoning. Furthermore, gender, SES, and ethnicity were also significantly related to this dimension of achievement. It is plausible that the spatial-mechanical items represent the kind of scientific thinking that is least emphasized in school and thus is most dependent on out-of-school opportunities to gain the relevant experience. Students representing different gender, ethnic, and socioeconomic groups may differ in these opportunities to learn, on average, more than they do in school learning. These differences, in turn, are reflected in the average performance of these groups of students on these kinds of items. Although some of the regression coefficients were small, and the variability within groups quite large, the presence of such selective group effects indicates important differences in prior student experiences over which teachers have no control; these differentials must be taken into consideration in further educational evaluations using NELS:88 data.

Comparisons between science and mathematics. We can add to our summary here by comparing the present findings for 8th and 10th grade science achievement with those obtained for mathematics achievement in the preceding report (see Kupermintz, et al., submitted). There were some clear differences between the two subject matter domains.

First, achievement patterns in science were more heterogeneous than in math. Two mathematics achievement factors were identified -- one for knowledge and one for reasoning -- at both 8th and 10th grade levels. In science, a far greater number of factors were required to account for student performance differences and these were qualitatively different at 8th and 10th grade levels. Further, the science factors reflected different types of knowledge and reasoning combinations. For example, we identified two knowledge-oriented factors in the 8th grade, e.g., chemistry knowledge and elementary science, but no 10th grade factors were exclusively knowledge-oriented. The 10th grade factors did reflect to varying degrees different topical domains, but they also seemed to distinguish different kinds of reasoning processes, as shown for example in the distinction between the reasoning required by quantitative science items and that involved in spatial-mechanical problems. In general, the science factors were more varied than those in math.

These findings make sense given the different nature of most mathematics and science course sequences. Mathematics courses tend to be arranged in hierarchical sequence often involving different tracks. The effect of this tracking is clearly evident in patterns of student achievement; for example, taking algebra in the 8th grade was a significant predictor of later math achievement. In science, the program or track variables provided little prediction beyond the effects of courses, suggesting that specific course exposure is more important than an overall program effect for explaining science achievement. Furthermore, other NELS:88 data indicate greater diversity in science course-taking sequences as compared to mathematics, at least through 10th grade. This might partially explain the more heterogeneous nature of science achievement.

If there is implicit tracking in science, it is likely reflected in course choices rather than some broader course sequence or program structure. However, because high achievement in quantitative sciences such as chemistry requires mathematical ability, different programs in mathematics can also produce de facto tracking in science, with less mathematically-inclined students avoiding chemistry or being counseled into lower level courses. Because we controlled for prior mathematics achievement, the salience of such tracking in our results was diminished. It seems likely that the effect of tracking in science is more nebulous and complex than in mathematics, and reflects the more heterogeneous and less hierarchical nature of high school science programs.

As noted, the mathematics factors also reflected a more explicit distinction between reasoning and knowledge than did the science factors, especially at the 10th grade. One plausible hypothesis is that mathematics teachers more sharply distinguish instructional practices that enhance reasoning abilities from those that develop concepts and computational skills than do science teachers. In our analysis of 10th grade science teaching practices, for example, we found emphasis on "facts" and on "problem solving" highly correlated. In mathematics, on the other hand, there were distinct differences between teacher emphasis on higher-order thinking and emphasis on facts and computation. This difference may in part reflect the different nature and status of facts in mathematics versus science. Facts in mathematics relate heavily to procedures, and often are addressed by separate drill and practice exercises at least at lower grades. Facts in science relate more to substantive terms, concepts and general principles. It may be that factual knowledge and reasoning are more integrated in science, and easier for science teachers to integrate in instruction.

Although some differences between mathematics and science may reflect instructional and subject-matter differences, some might also be explained by the nature of the items in the two surveys. For example, mathematics teachers reported on such practices as emphasis on speedy computation, whereas no comparable items were administered to science teachers. As a result, we have no way of knowing if emphasis on computation is an important positive or negative variable in science teaching, as it is in mathematics. Future surveys could include more common questions of this nature across domains, in addition to domain specialized questions.

Opportunity to learn. We can also summarize here briefly the results that bear most directly on the issue of opportunity to learn. Within the categories of variables we have investigated, opportunity to learn is perhaps most directly addressed by course taking and instructional emphasis variables. But outside-of-school opportunities to learn should also be considered.

In mathematics, it clearly matters that students take algebra and geometry, and the earlier the better. It seems to matter a bit more for knowledge than for reasoning development. In contrast, general math courses appear detrimental, at least to the kinds of performances called for on the 10th grade NELS:88 math tests. It also matters that teachers emphasize higher-order thinking and that students see teachers as emphasizing understanding, especially for knowledge development. A computer in the home is an outside opportunity, especially for reasoning development.

In science, it appears that taking chemistry promotes quantitative science knowledge, taking earth science promotes spatial-mechanical reasoning, and taking biology promotes basic science knowledge and reasoning. Teacher emphasis on problem solving and understanding seems especially important also in this third dimension. Visiting science museums seems especially important in relation to spatial-mechanical reasoning.

In both math and science, the effects of SES, gender, and ethnic differences also need careful further study in relation to the question of opportunity to learn. Math reasoning and spatial-mechanical reasoning in science show particularly strong effects in this regard. If school programs do not emphasize reasoning development in these areas and if the world outside of school affords experience differentially to such development, then both directly and indirectly some persons are advantaged while others are disadvantaged. Mathematical reasoning and spatial-mechanical reasoning are essential in both mathematics and science. Opportunity for all to learn both is a societal, not just an educational problem. Finally, it is important to reiterate that differentiating kinds of math and science achievement, replacing total scores with psychologically meaningful subscores, is an important step in improving our understanding of opportunity to learn.

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Table 1

NELS:88 Science Items and Descriptions

Master Item Number	8th Grade	10th Grade	Description
S01	1		Infer geologic history from facts about limestone deposits
S02	2		Identify components of solar system
S03	3	2	Read a graph depicting solubility of chemicals
S04	4	3	Choose an improvement for an experiment on mice
S05	5	4	Choose a statement about source of moon's light
S06	6	5	Identify the example of a simple reflex
S07	7		Choose viable way of communicating on moon
S08	8		Select statement about position of sun, moon, earth in diagram
S09	9		Identify source of oxygen in ocean water
S10	10	1	Choose the property used to classify a list of substances
S11	11		Explain lower freezing temperature of ocean water
S12	12	6	Answer question about the earth's orbit
S13	13		Infer use of oxygen from description of condition of aquarium
S14	14	7	Estimate temperature of a mixture
S15	15	8	Select a statement about the process of respiration
S16	16	9	Read a graph depicting digestion of a protein by an enzyme
S17	17	10	Explain location of marine algea
S18	18	11	Choose best indication of an approaching storm
S19	19	12	Choose the alternative that is not a chemical change
S20	20	13	Infer statement from results of an experiment using a filter
S21	21	14	Explain reason for late afternoon breeze from the ocean
S22	22	15	Select basis for a statement about a food chain
S23	23	16	Interpret symbols describing a chemical reaction
S24	24	17	Differentiate statements based on a model or an observation
S25	25	18	Describe color of offspring from a guinea pig cross
S26		19	Calculate a mass given density and dimensions
S27		20	Locate the balance point of a weighted lever
S28		21	Interpret a contour map
S29		22	Identify diagram depicting path of light through camera lens
S30		23	Calculate grams of a substance given its half life
S31		24	Read population graph; identify equilibrium point
S32		25	Identify cause of fire from overloaded circuit

Source: Rock, Pollack, Owings, & Hafner (1990)

Table 2

Proposed Science Subscales and Interpretations for Preliminary 8th Grade and Revised 8th and 10th Grade Analyses

Components from Preliminary 8th Grade Analysis

SC1: **Elementary Achievement**
Everyday or elementary level science achievement.

- S1a: **Elementary Knowledge (items 2, 3, 5, 7, 8, 12)**
  Items that require little more than non formal knowledge. All five astronomy items are in this subscore, but similarity is not primarily due to content.

- S1b: **Elementary Knowledge with Reasoning (items 4, 6, 9, 13)**
  Items that require non formal knowledge, but also some reasoning. All four have life science content.

SC2: **Formal Achievement**
School-based and advanced, formal science achievement.

- S2a: **Basic Formal Achievement (items 10, 14, 18, 19, 25)**
  Items that primarily call on formal knowledge, but some reasoning is involved. The content is basic chemistry and physics (e.g., states of matter, physical versus chemical change).

- S2b: **Advanced Formal Achievement (items 1, 17, 20, 24)**
  Of the whole test these items require the most integration of formal (textbook type) school knowledge and reasoning.

SC3: **Reasoning (items 15 and 22)**
Items that measure mostly reasoning. Nonsubstantive reasoning might be particularly involved in students' correct answers.

SC4: **Difficult Outliers (items 11, 16, 21, 23)**
Difficult items that do not fall in any of the other groups

Table 2 - cont.

Factors from Revised 8th Grade Analysis

SR: **Scientific Reasoning**
Items that require manipulation of equations, interpretation of graphs, and hypothesis formation. Includes S1b and most SC4 items.

CK: **Chemistry Knowledge**
Items that call for concepts such as mixtures, compounds, chemical change, and solubility, but few reasoning demands. Includes some SC2 items.

ES: **Everyday or Elementary Science**
Items that call for knowledge easily learned outside of school. Includes most S1a and some S1b and SC2 items.

RK: **Reasoning with Knowledge**
Items that require reasoning applied to formal science concepts. Science terms appear in response options.

Factors from Revised 10th Grade Analysis

QS: **Quantitative Science**
Items that require mathematical operations and/or chemistry knowledge. Includes CK and some SR items from 8th grade.

SM: **Spatial-Mechanical Reasoning**
Items that require comprehension of maps, diagrams of physical systems, and reasoning about them.

BKR: **Basic Knowledge and Reasoning**
Items that require knowledge of basic concepts and their application in simple reasoning situations. Includes some SR and ES items from 8th grade.

Table 3

Factor Loadings From Full Information Factor Analysis of NELS:88 Science Items in 8th and 10th Grades, After Promax Rotation (N=5041)

	8th Grade				10th Grade		
Factor	SR	CK	ES	RK	QS	SM	BKR
S23	44*	33	-19	23	99*	03	-23
S26					74*	16	-04
S16	40*	17	13	14	60*	01	03
S20	05	99*	-14	-08	64*	-01	05
S10	-02	47*	28	06	57*	18	05
S19	09	49*	13	14	45*	17	10
S03	05	27*	19	-03	36*	-08	30
S21	33	-08	-05	71*	38*	08	24
S30					39*	35	13
S25	19	11	26*	-05	34*	-01	21
S31					33*	05	31
S18	01	01	11	71*	29*	26	18
S14	08	14	32*	33	37	41*	11
S27					23	66*	-09
S28					00	62*	21
S29					-03	64*	14
S12	-18	05	44*	22	-04	46*	35
S01	38*	-19	37	26			
S05	19	-21	73*	09	-39	28	89*
S06	32	07	61*	-21	-05	00	79*
S15	11	14	26*	-03	-04	-11	59*
S17	19	-08	22	49*	11	18	57*
S22	36*	-11	04	30	09	-06	43*
S32					-13	04	46*
S04	53*	01	17	-12	30	-15	36*
S24	22	00	35*	10	15	15	29*
S02	-11	01	39*	20			
S07	10	-05	45*	-01			
S08	-06	07	47*	00			
S09	01	-12	65*	-12			
S13	19	-03	45*	-08			
S11	-01	08	14	23*			

Notes.

Decimal points omitted

* indicates highest loading for each item

Table 4

NELS:88 8th Grade Science Items with Process, Content, and Subscale Designations

	Content							
Process	Earth		Life		Chemistry		Scientific method	
Declarative knowledge	ES	2	ES	6	CK	10		
	ES	5	ES	9	CK	19		
	ES	8	ES	15				
	ES	12						
	RK	18						
Comprehension	ES	7	SR	16	CK	3	ES	24
	RK	21	RK	17	RK	11		
Problem solving	SR-ES	1	ES	13	ES	14	SR	4
			SR	22	CK	20		
			ES	25	SR	23		

Table 5

Instructional Variables with Corresponding Items from the NELS:88 Science Teacher Questionnaire

Factor and Item Identifier[a]	Item Description
DISCUSSION	
F1T2_18E	Use of student-led discussion
F1T2_18C	Use of whole-group instruction
F1T2_18H	Use of oral reports
F1T2_18D	Oral question response
F1T2_12B	Use of other reading materials
INDIVIDUALIZATION	
F1T2_18F	Use of working in small groups
F1T2_16B	Time spent instructing small groups
F1T2_16F	Time spent instructing individuals
F1T2_16G	Time spent conducting lab periods
ADMINISTRATIVE TASKS	
F1T2_16F	Time spent on administrative tasks
F1T2_16D	Time spent maintaining order
F1T2_16E	Time spent administering tests/quizzes
F1T2_16C	Time spent instructing individuals
F1T2_18G	Use of written assignments
TRADITIONAL INSTRUCTION	
F1T2_18A	Use of lecture
F1T2_16A	Time spent instructing whole class
F1T2_18D	Use of oral question response
MATERIALS/AUDIO-VISUALS	
F1T2_18B	Use of film
F1T2_12C	Use of audio-visual materials
TEXTBOOK INSTRUCTION	
F1T2_12A	Use of textbook
F1T2_12B	Use of other reading material
F1T2_18G	Use of written assignments
EVERYDAY SCIENCE	
F1T2S19G	Emphasis on science in life
F1T2S19I	Apply science to environment
F1T2S19H	Emphasis on observation skills
F1T2S19A	Emphasis on interest in science
EXPERIMENTS	
F1T2S20C	How often do experiments
F1T2S20E	How often report on experiments
F1T2S20D	How often demonstrate experiments
F1T2S19B[b]	Emphasis on scientific facts
F1T2S19E[b]	Emphasis on problem solving

Notes.

[a] Item identifiers are variable names on NELS:88 public data release

[b] Single-item indicators.

Table 6

Regression Results for 10th Grade Quantitative Science (N=4807)

VARIABLE	STUDENT	COURSE/PRG	INSTRUCT	OUTSIDE
INTERCEPT	-04	-03	00	03
PRIOR ACHIEVEMENT				
SR 8	06 *	07 *	06 *	08 *
CK 8	12 *	12 *	12 *	12 *
ES 8	05 *	06 *	07 *	05 *
PK 8	13 *	15 *	15 *	15 *
READING 8	15 *	15 *	13 *	15 *
MATH KNOWLEDGE 8	15 *	14 *	14 *	13 *
MATH REASONING 8	21 *	22 *	22 *	24 *
STUDENT				
ABSENT	-03 *			
GENDER	07 *			
SES	07 *			
ASIAN	09			
BLACK	-03			
HISPANIC	-03			
MATH ANX	01			
LUCK 8	00			
NEG SELF 8	-01			
POS SELF 8	00			
SCIENCE ATT 8	06 *			
MATH ATT 8	03			
COURSE/PROGRAM				
ADVANCED TRACK		05		
GENERAL TRACK		-06		
GIFTED PRG		03		
BIOLOGY TAKEN		-04		
CHEMISTRY TAKEN		21 *		
EARTH SCI TAKEN		02		
GENERAL SCI TAKEN		05		
PHYSICS TAKEN		-07		
PHYSICAL SCI TAKEN		06 *		
PRIN TECH TAKEN		-05		
ALGEBRA IN 8TH		02		
INSTRUCTIONAL				
DISCUSSION			-03	
INDIVIDUALIZATION			00	
ADMINISTATIVE TASKS			-02	
TRADITIONAL INSTRUCT			01	
MATERIALS/AV			-03 *	
TEXTBOOK INSTRUCT			00	
EVERYDAY SCIENCE			-03	
EXPERIMENTS			04 *	
FACTS			-02	
PROBLEM SOLVING			04 *	
UNDERSTANDING			04 *	
HOMEWORK DISCUSS			-01	
TIME ON HOMEWORK			-02	
OUTSIDE				
SCIENCE MUSEUMS				07 *
SCIENCE CLUB				00
HOURS TV				00
COMPUTER IN HOME				08 *
COMPUTER CLASS				-04
HELP WITH HOMEWORK				-01
R-SQUARED	52	51	51	50

Note
Decimal points omitted
*p<.01

Table 7

Regression Results for 10th Grade Spatial/Mechanical Reasoning (N=4807)

VARIABLE	STUDENT	COURSE/PRG	INSTRUCT	OUTSIDE
INTERCEPT	-20	02	00	-09
PRIOR ACHIEVEMENT				
SR 8	-03	-05 *	-05 *	-05 *
CK 8	04 *	04 *	05 *	04 *
ES 8	23 *	27 *	26 *	27 *
RK 8	15 *	21 *	22 *	20 *
READING 8	05 *	00	00	00
MATH KNOWLEDGE 8	04	02	04	01
MATH REASONING 8	21 *	28 *	27 *	27 *
STUDENT				
ABSENT	-02			
GENDER	48 *			
SES	08 *			
ASIAN	01			
BLACK	-27 *			
HISPANIC	-11 *			
MATH ANX	-01			
LUCK 8	-01			
NEG SELF 8	-01			
POS SELF 8	-02			
SCIENCE ATT 8	02			
MATH ATT 8	00			
COURSE/PROGRAM				
ADVANCED TRACK		02		
GENERAL TRACK		-04		
GIFTED PRG		-02		
BIOLOGY TAKEN		-06		
CHEMISTRY TAKEN		01		
EARTH SCI TAKEN		10 *		
GENERAL SCI TAKEN		01		
PHYSICS TAKEN		06		
PHYSICAL SCI TAKEN		06		
PRIN TECH TAKEN		-13		
ALGEBRA IN 8TH		02		
INSTRUCTIONAL				
DISCUSSION			00	
INDIVIDUALIZATION			01	
ADMINISTATIVE TASKS			01	
TRADITIONAL INSTRUCT			-01	
MATERIALS/AV			02	
TEXTBOOK INSTRUCT			-01	
EVERYDAY SCIENCE			-01	
EXPERIMENTS			02	
FACTS			-01	
PROBLEM SOLVING			00	
UNDERSTANDING			01	
HOMEWORK DISCUSS			00	
TIME ON HOMEWORK			00	
OUTSIDE				
SCIENCE MUSEUMS				13 *
SCIENCE CLUB				07
HOURS TV				-01
COMPUTER IN HOME				10 *
COMPUTER CLASS				00
HELP WITH HOMEWORK				-01
R-SQUARED	48	41	41	40

Note
Decimal points omitted
*p<.01

Table 8

Regression Results for 10th Grade Basic Knowledge and Reasoning (N=4807)

VARIABLE	STUDENT	COURSE/PRG	INSTRUCT	OUTSIDE
INTERCEPT	01	-06	01	00
PRIOR ACHIEVEMENT				
SR 8	04 *	04 *	05 *	05 *
CK 8	01	03	01	02
ES 8	23 *	23 *	24 *	22 *
RK 8	08 *	10 *	09 *	09 *
READING 8	19 *	21 *	21 *	21 *
MATH KNOWLEDGE 8	05 *	04	04	05 *
MATH REASONING 8	15 *	16 *	16 *	14 *
STUDENT				
ABSENT	-06 *			
GENDER	02			
SES	05 *			
ASIAN	00			
BLACK	-14 *			
HISPANIC	-09			
MATH ANX	-01			
LUCK 8	-03			
NEG SELF 8	01			
POS SELF 8	-01			
SCIENCE ATT 8	04 *			
MATH ATT 8	-01			
COURSE/PROGRAM				
ADVANCED TRACK		02		
GENERAL TRACK		-07 *		
GIFTED PRG		01		
BIOLOGY TAKEN		12 *		
CHEMISTRY TAKEN		-05		
EARTH SCI TAKEN		02		
GENERAL SCI TAKEN		-07		
PHYSICS TAKEN		00		
PHYSICAL SCI TAKEN		00		
PRIN TECH TAKEN		-14		
ALGEBRA IN 8TH		00		
INSTRUCTIONAL				
DISCUSSION			00	
INDIVIDUALIZATION			01	
ADMINISTATIVE TASKS			-03	
TRADITIONAL INSTRUCT			01	
MATERIALS/AV			02	
TEXTBOOK INSTRUCT			00	
EVERYDAY SCIENCE			00	
EXPERIMENTS			-01	
FACTS			00	
PROBLEM SOLVING			05 *	
UNDERSTANDING			03 *	
HOMEWORK DISCUSS			00	
TIME ON HOMEWORK			02	
OUTSIDE				
SCIENCE MUSEUMS				06
SCIENCE CLUB				06
HOURS TV				-01
COMPUTER IN HOME				04
COMPUTER CLASS				-02
HELP WITH HOMEWORK				-01
R-SQUARED	46	45	45	43

Note
Decimal points omitted
*p<.01

Table 9

Regression Results for Overall Models for 10th Grade Quantitative Science, Spatial/Mechanical Reasoning, Basic Knowledge and Reasoning, and Total Science IRT Score (N=4807)

	QS	SM	BKR	TOTAL IRT
INTERCEPT	-06	-22	-07	-05
PRIOR ACHIEVEMENT				
SR 8	07 *	-03 *	04 *	03 *
CK 8	11 *	04 *	02	05 *
ES 8	05 *	20 *	23 *	19 *
RK 8	13 *	15 *	08 *	13 *
READING 8	14 *	06 *	19 *	16 *
MATH KNOWLEDGE 8	13 *	04	04	09 *
MATH REASONING 8	20 *	21 *	15 *	22 *
STUDENT				
ABSENT	-02	-02	-05 *	-04 *
GENDER	08 *	46 *	02	19 *
SES	05 *	08 *	03	06 *
ASIAN	05	-03	-03	00
BLACK	-06	-30 *	-17 *	-19 *
HISPANIC	-07	-15 *	-10 *	-12 *
SCIENCE ATT 8	05	02	-03 *	-04 *
COURSE/PROGRAM				
ADVANCED TRACK	05	02	01	04
GENERAL TRACK	-03	-04	-06 *	-05 *
BIOLOGY TAKEN	-05	-03	12 *	03
CHEMISTRY TAKEN	14 *	01	-09 *	04
EARTH SCI TAKEN	00	08 *	02	02
PHYSICAL SCI TAKEN	04	05	00	02
INSTRUCTIONAL				
MATERIALS/AV	-01	02	02	02
EXPERIMENTS	03	03	00	02
PROBLEM SOLVING	03	00	05 *	03 *
UNDERSTANDING	03	-01	03 *	02
OUTSIDE				
SCIENCE MUSEUMS	04	06 *	01	04
COMPUTER IN HOME	03	03	01	03
R-SQUARED	52	48	46	65

Note
Decimal points omitted
*p<.01