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ABSTRACT

This study used data collected during 1981-82 from a random sample of 1,960 9-year-old students from 124 elementary schools involved in a national assessment of educational progress in science. The database was used in secondary analyses which probed the validity of a model of educational productivity involving a set of nine aptitudinal, instructional, and environmental variables which require optimization to increase student learning. When controlled for other factors, ability, motivation, class environment, home environment, amount of television viewing (negative direction), sex, and race were all found to be significantly related to achievement. For an attitude outcome, the factors linked with attitudinal attainment were ability, motivation, class environment, and race. These results for 9-year-olds were compared with those emerging from secondary analyses of data provided by 1,950 17-year-olds and 2,025 13-year-olds participating in the same assessment. Overall, the findings supported the model of educational productivity and sugggested that science students' achievement and attitude are influenced jointly by a number of factors rather than one or two dominant ones. The study also attests to the potential value of science education researchers performing secondary analyses on the high-quality random databases generated as part of national assessments. (Author/JN)

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EDUCATIONAL PRODUCTIVITY IN SCIENCE EDUCATION: SECONDARY ANALYSIS OF NATIONAL ASSESSMENT IN SCIENCE DATA

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Abstract

This study made use of data collected during 1981-82 from a random sample of 1,960 nine-year-old students from 124 elementary schools involved in a national assessment of educational progress in science sponsored by the National Science Foundation. This data base was used in secondary analyses which probed the validity of a model of educational productivity involving a set of nine aptitudinal, instructional, and environmental variables which require optimization to increase student learning. When controlled for other factors, ability, motivation, class environment, home environment, amount of television viewing (negative direction), gender, and race were all found to be significantly related to achievement. For an attitude outcome, the factors linked with attitudinal attainment were ability, motivation, class environment, and race. These results for 9-year-olds were compared with those emerging from secondary analyses of data provided by 1,950 17-year-old and 2,025 13-year olds participating in the same national assessment. Overall the findings supported the model of educational productivity and suggested that science students' achievement and attitude are influenced jointly by a number of factors rather than one or two dominant ones. Also the study attests to the potential value of science education researchers performing secondary analyses on the high quality random data bases generated as part of national assessments.

Given the link between scientific literacy and economic productivity, it is highly desirable that the scientific literacy of American youth is high. But the current level is a matter of grave national concern because science and mathematics achievement scores have declined over the last decade or two and because they have fallen behind those of youth in other industrialized nations (Comber & Keeves, 1973; Husen, 1967; Jones, 1981; Walberg, 1983; National Commission on Excellence in Education, 1983). Consequently, concerted efforts need to be made, first, to identify through educational research those factors which lead to improved scientific literacy and, second, to change schools to optimize the factors which will enhance the science performance of students.

The present research aims to identify factors which are linked to the science achievement and attitude scores of students at several different age levels. In particular, based on many comprehensive syntheses of prior research, a model of educational productivity is proposed which incorporates a set of factors which powerfully and consistently predict student outcomes. Firstly, this model is tested with data collected from a large sample of 9-year old students involved in the National Assessment in Science. Secondly, the results for 9-year-olds are compared with those for 17- and 13-year old students involved in the same assessment. Thirdly, implications are drawn for improving scientific literacy.

MODEL OF EDUCATIONAL PRODUCTIVITY

According to Walberg's theory of educational productivity, nine factors require optimization to increase student achievement of cognitive and affective outcomes (Horn & Walberg, 1984; Walberg, 1981, 1983, 1984a, b; Walberg, Harnisch & Tsai, 1984; Walberg, Tsai & Harnisch, 1984; Walberg & Shanahan, in press). These factors are the student aptitudinal variables of (1) ability or prior achievement, (2) age, (3) motivation or self concept as indicated by personality tests or willingness to persevere on learning tasks, the instructional variables of (4) quantity of instruction, (5) the quality of the instructional experience, and educationally stimulating psychological aspects of the (6) home environment, (7) the classroom or school environment and (8) the peer group environment, and (9) the mass media (especially television). This model recognizes the complexity of human learning but still is parsimonious in that it converges on the least number of factors which powerfully and consistently predict student outcomes. A major strength of the model is that the nine productive factors largely were identified from syntheses of about 3,000 individual studies of factors related to student learning (e.g., Frederick & Walberg, 1980; Graue, Weinstein & Walberg, 1983; Iverson & Walberg, 1982; Uguroglu & Walberg, 1979; Walberg, 1984a, b; Williams, Haertel, Haertel & Walberg, 1982).

Few prior intensive experiments and quasi-experiments are national in scope, and most analyse only one or two of the factors and sample limited populations within a school or community. They are often strong on observational technique, measurement, verification, and random assignment to treatments (in short, internal validity), but they are often weak in generalizability or external validity since they do not sample rigorously from large, well defined populations. Survey research has complementary strengths and weaknesses: it often draws large, stratified, random samples of national populations and measures more factors but sacrifices internal validity since the factors are usually measured cross sectionally and perhaps superficially with only a few items. Also survey research can control statistically to some extent for multiple causes and can be more causally convincing than quasi-experiments controlled only for one or two covariates. Consequently, the complementarity of intensive and extensive studies is important since powerful effects should emerge consistently from either form of research.

As most of the available evidence was assembled from data gathered a decade or more ago, it was considered useful to test the generality of the results with more current data and to extend the set of variables included. Thus, the purpose of the present study was to compare regressions of National Assessment in Science data recently collected in 1981-82 with previous regressions and syntheses of smaller-scale experimental and quasi experimental studies.

NATIONAL ASSESSMENT IN SCIENCE

The National Assessment of Educational Progress (NAEP) was established in the USA in 1969 to assess periodically students' knowledge of various school subject areas. In science, national assessments were conducted by NAEP in 1969 70, 1972 73, and 1976 77. But, because of legislative decisions and financial constraints, the National Institute of Education postponed the next fully fledged NAEP science assessment until the late 1980s, thus causing an anticipated gap of approximately 13 years between successive assessments. Many science educators were concerned that this hiatus would permit emerging problems to go unchecked. Consequently, during 1981 and 1982, the National Science

Foundation funded a science assessment under the direction of Wayne Welch at the University of Minnesota to fill this void. The project involved the collection of a data on many variables including student cognitive and affective outcomes and characteristics of the home, the community, and the school (Hueftle, Rakow & Welch, 1983; Welch, 1985).

This National Assessment in Science involved a national random sample of approximately 18,000 students of ages 17, 13, and 9 in about 700 schools in the USA. In order to minimize testing time per student, the total test battery for 17- and 13-year-olds was divided into four separate test booklets, each containing nearly 100 separate items. In the case of 9-year-old students, there was only one booklet and this was responded to by all students in the sample. To ensure a broad sample of schools, an average of 16 students per school answered a particular test booklet. The size of the subsample responding to any given test booklet was approximately 2,000 students.

The 1981-82 assessment was in many ways different from previous NAEP assessments. It was funded by NSF, not NIE. It focussed on achievement in the science-technology-society realm and contained a large number of attitude items. Because it was designed to satisfy some science education research purposes, more information than usual was gathered on student and school characteristics (e.g., science anxiety, class enrolments, parents' occupation, and computer usage). Furthermore, the grant was made to the University of Minnesota which subcontracted to NAEP for test printing, sample selection, test administration and item scoring; staff at Minnesota were responsible for item selection, writing background questions, data analysis, and reporting. Despite those differences, however, the 1981-82 assessment contained many of the items used in previous assessments, thus reducing costs and permitting longitudinal comparisons.

Because the main purposes of this and previous large-scale assessments were to assess the status of scientific literacy among various groups and to compare this with data from past assessments, some of the key information is the proportion of respondents answering each item correctly. These proportions typically are reported for different subgroups of students representing different geographic regions, genders, races, and types of community. Often item means in a particular area (e.g., physics, attitude to science) are averaged and changes between successive assessments are noted. For example, Rakow, Welch, and Hueftle (1984) report this type of data and provide the interesting conclusion that, whereas 9-year-olds increased a small amount in their science achievement over the past five years, 13-year-olds showed essentially no change while 17-year-olds experienced a decline. Also Welch (1985) reports generally low attitudes at all age levels and declines in attitudes over the last five years in several areas among both 17- and 13- year olds. Other examples of the use of data from the recent National Assessment in Science include examining secondary school science enrolments in the United States (Welch, Harris, & Anderson, in press), inequities in opportunities for computer usage in schools (Anderson, Welch, & Harris, 1984), and perceptions of secondary school students toward women in science (Welch, Rakow, & Harris, 1984).

Because of the large number of individual test items answered by large numbers of students, the National Assessment in Science data provide an extremely useful basis for performing secondary analyses (Fraser & Tobin, 1985) which inter-relate variables (often defined in terms of subsets of individual items). In fact, as noted above, one of the specific purposes of the 1981-82 assessment recognized by the National Science Foundation was the provision of a data base for science education research. Some examples of secondary analyses of these data already completed are investigations of the stability of attitudes to science between junior and senior high school (Hofstein & Welch, 1984) and the influence of class attitudes and teacher image on student outcomes (Tamir, Welch & Rakow, in press). In particular, as the National Assessment in Science data included items which could be interpreted as measures of most of the factors in Walberg's educational productivity model, the present authors conducted secondary analyses for the purpose of probing the validity of the productivity model.

SECONDARY ANALYSIS FOR AGE 9

Operationalizing Variables for 9-Year-Olds

Data from the national assessment in science were used to operationalize two measures of student learning, namely achievement and attitude, and at least one measure of seven of the nine factors in the productivity model. Age was excluded because the sample consisted only of nine-year-olds and no suitable measure of peer group environment was available in the national assessment data.

The achievement measure consisted of 29 multiple-choice items covering science content, inquiry skills, and science-technology society interactions (e.g., health, land use, pollution, computers). The reliability of this measure was 0.79 (Cronbach alpha coefficient) for the sample of 1,960 students.

The attitude outcome measure consisted of 23 Likert-type items assessing opinions about the value of science, science careers, and the resolution of persistent societal problems (e.g., food shortages, energy waste, disease). Items were scored on a three-point scale (3 - positive response, 2 - neutral, 1 - negative response), thus the range of possible scores was 23-69. The alpha reliability of this scale was 0.69.

Ability was assessed with a set of five multiple-choice items measuring reasoning, classification, and mapping skills; the reliability of the scale was 0.61. Motivation was measured with 21 items about student involvement in science related activities (e.g., working with magnets, seeds, microscopes, thermometers, batteries); scale reliability was 0.71.

An indication of the quality of instruction was obtained by dividing the science teaching budget (as reported by the school principal) by the number of students in the school. Quantity of instruction was assessed by two variables, namely, the average number of hours of science taught each week in grades three and four and the number of hours per day spent on homework.

Class environment was measured by five items asking students how they felt during science classes (e.g., "happy", "interested"); the alpha reliability of the scale was 0.60. An indication of home environment was obtained in terms of the higher of either parent's education (using a 6-point scale ranging from "did not complete eighth grade" to "graduated from college"). The mass media environment was assessed in terms of the number of hours of television watched during the previous day.

In addition to the above factors in the productivity model, the present study involved the two extra variables of gender and race because they have been found to be good predictors of science learning in other studies. If the extra variables of gender and race prove to be significant independent predictors, this would suggest an omission in the original productivity model.

Appendix A contains more detailed information about the definitions of all the variable included in the study. Table I summarizes the means and standard deviations obtained for each learning outcome measure and productivity factor for the sample of 9-year-olds.

Insert Table I here

As can be seen from the above descriptions, indexes for several of the productivity factors are coarse, incomplete, and have limited reliability. This is a common problem facing the secondary analyst - factors must be operationalized from the available data. However, use of crude indicators for some of the factors would tend to lead to an underestimate of the magnitude of their associations with learning. It is likely, therefore, that studies involving better measures of the hypothesized factors would yield even stronger relationships than those found in this study.

Description of 9-Year-Old Sample

A stratified random sampling process was used to select the 1,960 nine-year-olds involved in the national assessment in science. The multi-staged selection process ensured proportional representation by region of the USA (namely, Northeast, Southeast, Central, and West) and size of community (ranging from large cities with more than 200,000 population to extreme rural areas of less than 10,000). Students were selected at random from the 124 randomly selected schools. Approximately 16 students in each school were tested under uniform testing conditions. Students were given test booklets with one exercise per page and a paced audio tape was used to speak the items aloud and provide a uniform time for answering.

Approximately two-thirds of the nine-year-olds were in the fourth grade at the time of testing, while one-third were in the third grade. About 80 per cent of the sample was white, with about equal numbers of boys and girls.

The response rate among the students initially selected for testing was 91 per cent. National assessment samples are among the most carefully chosen available to researchers, and test administration conditions are excellent. Research findings for the present sample, therefore, should be generalizable with confidence to the population of nine-year-olds in the USA.

Analyses and Results for Age 9

Intercorrelations among the two dependent variables and the 10 predictor variables are shown in Table I together with means and standard deviations. The correlation of 0.45 between the outcome measures, achievement and attitude, is considerably higher than values reported in recent meta-analyses. Willson (1983) reported a mean value of 0.17 for the 48 studies of elementary children he analysed, while Haladyna and Shaughnessy (1982) reported a median correlation of 0.15. Our higher value is probably due to the similarity of focus on socio-scientific topics in the attitude and achievement measures we used.

The student aptitude indicators of ability and motivation also were moderately related to achievement (with correlations of 0.48 and 0.25, respectively), as was race (correlation of 0.31). The correlations of achievement with quality and quantity of instruction were essentially zero, while the environmental factors bore moderate positive relationships to achievement, except for television viewing which was in the expected negative direction (Williams, Haertel, Haertel, & Walberg, 1982).

The highest simple correlations with attitude toward science were for class environment (0.36), motivation (0.31), and ability (0.23). As with achievement, the instructional factors had negligible correlations.

A multiple regression analysis was used for the achievement and attitude outcomes to examine simultaneously the effect of the full set of productivity factors. Because of collinearity among predictors, these multiple regression analyses provided the advantage of a multivariate test of the joint influence of the set of all factors on an outcome and an estimate of the effect of each individual factor when all other factors are held constant. Raw regression weights and their associated t ratios are reported in Table II for "full" and "reduced" models. A "backwards elimination" method was used to generate the reduced model by dropping nonsignificant predictors successively until all variables remaining had regression weights significantly different from zero.

Raw regression weights are reported because they indicate the change in the number of points on an outcome measure associated with a one-unit increment in each predictor variable when the remaining variables are held constant. For example, Table II shows that an increase of one point on the ability scale is associated with an increase of 1.43 points in achievement, while a decrease of one hour of television viewing is associated with a 0.13 point increase in achievement.

Insert Table II about here

For binary variables coded 0 and 1, regression weights can be interpreted directly as group differences. For instance, on achievement, boys scored 0.74 points higher than girls and whites scored 2.56 points higher than non-whites when all other factors were controlled. Thus, the average white male score 3.30 points (about two-thirds of a standard deviation) higher than non-white females. (Standardized beta weights for each factor can be calculated using the standard deviations provided in Table II by multiplying the raw regression weights by the ratio of the standard deviation of the predictor variable to that of the outcome measure).

The multiple correlation for the full set of predictors was 0.57 for achievement and 0.50 for attitude. The number of significant independent predictors was seven for the cognitive outcome and four for the affective outcome. When controlled for all other variables, ability, motivation, class environment, home environment, amount of television viewing (negative direction), gender, and race were all significantly related to achievement. The variables related to attitude, when controlled for other variables, were ability, movitivation, class environment, and race.

It is interesting to note that, among nine-year-olds, quantity and quality of schooling factors are not important predictors of science learning. Rather it is the individual and environmental characteristics that are most highly related. This may not be too surprising given that these students have only been in school three or four years and, furthermore, little science is taught in the primary grades (Weiss, 1978). The emphasis on reading and arithmetic seems to crowd science out of the curriculum at this age level. The national assessment in science revealed that students in Grades K-2 on average spent only 64 minutes per week on science related activities as reported by school administrators. The sample of nine-year-olds used in this paper had a mean of 86 minutes (1.43 hours) of science per week (see Table I).

Variation in student cognitive achievement at this age level appears largely a function of student aptitudes (ability, motivation), the influence of the class, home, and mass media environment, and the two additional vakiable of gender and sex (see Table II). Although it is somewhat disappointing to find that instructional quality or quantity bore such weak relationships to achievement, several of the significant predictors of achievement are alterable. In particular, motivation, class environment, and television watching habits could be changed. It appears that cognitive learning could be enhanced through attempts to improve student motivation (indexed by involvement in science related activities such as visiting zoos or museums), to create a more positive classroom environment, and to encourage students to watch less television. Changing each of these factors by one unit would be associated with an increase of 2.52 points in achievement, which is more than one-half a standard deviation. Put another way, an increase of 0.5 standard deviations would place a student originally at the 50th percentile at the 69th percentile.

Attitude toward science is related to ability, motivation, class environment, and race when other factors are constant. Motivation and classroom environment are school-alterable factors to some extent, and unit increases in each would be associated with a gain in attitude of 4.98 points (about four-fifths of a standard deviation).

This study suggests that race and gender need to be included in a model of educational productivity, at least for science learning among elementary school students. Both were significant independent predictors of achievement and race was a predictor of attitude in the present research. Although these factors are not alterable, the results support the claim that special programs may be needed to overcome the differential science achievement that starts appearing among girls and non-whites as early as the third grade.

The present findings suggest that, in the early grades, the impact of schooling lags behind the influence of aptitudinal and environmental factors. Among nine-year-olds, the influence of quality and quantity of instruction is virtually zero. It seems that students must be in school for several years before it is possible to detect the impact of schooling on science learning. To some, this finding might be construed as a failure of our primary science programs. We prefer to view it as an opportunity. If society deems it important to develop science learning in the early years of schooling, there is room for this to occur.

SECONDARY ANALYSES FOR 17- AND 13-YEAR-OLDS

Whereas the previous section reported the results of a test of the model of educational productivity among the 9-year-olds involved in the National Assessment in Science, the purpose of this section is to compare the findings for 9-year-olds with the results of analogous secondary analyses performed on data obtained from 17- and 13-year-old students involved in the same national assessment. As with the 9-year-old sample, the first step in the secondary analyses of data for 17- and 13-year-olds involved using the data base to operationalize two measures of student outcomes and at least one measure of seven of the nine productive factors in Walberg's model. Appendix B provides detailed descriptions and operational definitions of each of the variables involved at these two age levels. Operationalization of several of these factors was guided by Rakow's (1984) definitions of variables in a study of inquiry skill knowledge among the 17-year-old sample involved in the National Assessment in Science. Table III provides descriptive information for each variable for the two age groups including the number of items, the alpha reliability (where applicable), the mean, and the standard deviation.

Insert Table III about here

The cognitive achievement measure consisted of 49 multiple-choice items covering content topics, inquiry skills, and understanding of societal issues (alpha reliability = 0.87 for 17-year-olds and 0.80 for 13-year-olds). The science attitude measure consisted of 19 Likert-type items with five response alternatives assessing opinions about the value of science and willingness to solve societal problems (alpha reliability = 0.72 for 17-year-olds and 0.68 for 13-yearolds).

Ability was assessed with a self-report item asking about students' previous grades in school. Age was excluded because each of the samples consisted of students all of the same age (namely, either 17 or 13 years) and therefore age exhibited limited variability. Motivation was assessed with 8 items asking about the frequency of voluntary participation in science-related activities (alpha reliability = 0.82 for 17-year-olds and 0.78 for 13-year-olds).

Quality of instruction was assessed by two different variables. First, the average science teaching budget per pupil (as reported by the school principal) was used. Second, students' attitudes toward their science teacher were assessed by 5 Likert-type items with and alpha reliability of 0.72 for 17-year-olds and 0.66 for 13-year-olds. The quantity of instruction also was assessed by two variables, namely, the amount of science and the average number of hours of homework per day. The amount of science was defined for 17-year-olds in terms of the total number of semesters of different science courses taken in Grades 9-12, and for 13-year-olds in terms of whether the student took 0, 1, or 2 science courses over a two-year period.

The class environment was measured by 6 items asking students how they felt during science classes (alpha reliability = 0.78 for 17-year-olds and 0.68 for 13-year-olds). Home environment was assessed in terms of the higher of the ratings for father's and mother's education coded on a scale of 1 to 6. The items included in the National Assessment in Science did not permit the peer group environment to be assessed at any age level. As with the 9-year-old sample, the mass media environment was assessed in terms of the number of hours of television watched during the previous day, and the two extra variable of gender and race were included.

The multiple-choice achievement measures used in this study are not without controversy. For example, they emphasize recognition more than recall of the best answer, and students who achieve high scores on such tests are not necessarily able to apply their knowledge in the real world or to create new knowledge. Nonetheless, such tests provide at least a broad, reliable sample of what students know and, without such basic knowledge or literacy, students cannot be expected to reach high thought levels. As well, testing authorities generally agree that objective tests can be used to assess important understanding and critical thinking capacities.

The sample of 17- and 13-year olds, like the sample of 9-year-olds previously described, was drawn using a stratified, two-stage probability design. The sample provided probabilities proportional to size to represent all regions and community sizes. Oversampling of low-income and rural areas ensured adequate representation of these groups. In the second stage of sampling, 125 schools were randomly chosen with probabilities proportional to the size of the school. Finally, random samples of about 16 students were selected from each of these schools. In an attempt to ensure uniformity of testing conditions, again test administrators visited each school to give the instruments using a timed and paced audiotape.

The total sample included approximately 8,000 17-year-olds in about 300 schools (with approximately 2,000 of these students responding to each of the four separate test booklets used as part of a matrix sampling plan) and approximately 8,000 13-year-olds in about 300 schools (again with approximately 2,000 students responding to each of four different test booklets). For the purposes of testing the educational productivity model in the present study, a choice was made from the four separate test booklets answered by 17- and 13-year-olds of the one which contained the most appropriate items for assessing the variables included in the productivity model. In fact, Booklet 21 was used with both of those age groups. The exact sample sizes for the analyses reported below are 1,955 17-year-olds and 2,025 13-year-olds.

COMPARISON OF RESULTS FOR AGES 17, 13, AND 9

Table IV compares the results obtained for 17-, 13- and 9-year-old students when the effect of each productivity factor on student achievement and attitude was investigated using multiple regression analyses in which the whole set of predictors was regressed on achievement or attitude. The information reported for each productive factor is the raw regression weight, b, together with significance level from of a t test of whether the magnitude of the regression weight is greater than zero. The bottom of Table IV also shows that the multiple correlations for the whole of a set of predictor variables ranged from 0.50 to 0 59 for different age groups for different outcomes.

Insert Table IV about here

In interpreting consistency across age groups of the multiple regression results in Table IV, it should be remembered that certain differences exist between the three age levels in the definition of some of the variables. The results for 17-year-olds in Table IV show that, of the 11 predictors of science achievement, all 11 were found to have statistically significant regression weights. In the case of 13-year-olds, 10 of these predictors (with the exception being attitude to the teacher) again were significant independent predictors of achievement. Of the 10 predictors of 9-year-olds' achievement, Table IV shows that 7 were significant when other independent variable were held fixed. Overall, then, there is quite high consistency of achievement results across the three different age groups since statistically significant regression weights were found for all three age groups for as many as seven of the productivity factors, namely, ability, motivation, class environment, home environment, television viewing, gender, and race.

For the science attitude results reported in Table IV, again there is good consistency across the three age groups. In fact, there are four variables which proved to be significant independent predictors at all age levels; these are ability, motivation, attitude to the teacher (which was measured at ages 17 and 13 only), and class environment. As well, there are three other independent variables which were found consistently to be nonsignificant independent predictors at each of the three ages; these are science teaching budget, amount of science, and gender. For the remaining four productivity factors, significant relationships emerged at one or two age levels, but not at all three. In particular, amount of homework was a significant independent predictor of attitudes for 17- and 13-year-olds only; the home environment was a significant independent predictor for 17-year-olds only; amount of television viewing was a significant predictor (in the negative direction) at age 13 only; and race was significantly associated with attitude to science only amoung the 9-year-old sample.

In the paragraphs below, the results for each individual productivity factor are disdussed in turn.

Ability. As expected, ability is among the strongest and more consistent predictors of both science achievement and attitude. In fact, when all other factors were held constant, ability was found to be significantly related to both achievement and attitude for the 17-, 13-, and 9-year-old samples.

Motivation. Similary, as would be anticipated from reviews of the effects of motivation and achievement (Uguroglu & Walberg, 1979), motivation also was found to be a significant independent predictor of both achievement and attitude at all three age levels.

Quality of instruction. The first measure of quality of instruction, namely, science teaching budget, turned out to be a relatively weak predictor of student outcomes when other variables were held constant. Science teaching budget was found to be a significant independent predictor of achievement ($p<0.05$) for 17- and 13-year-olds, but not for 9-year-olds. Also teaching budget was not significantly related to attitude scores at any age level. The regression weights for achievement suggest that, with other factors fixed, an increase of $1 per pupil in the science teaching budget is associated with an increase in achievement of only 0.06 points for 17-year-olds and 0.04 points for 13-year-olds. The second variable assessing quality of instruction, namely, student attitude to the teacher, was a significant independent predictor of achievement among 17-year-olds and a significant independent predictor of attitudes among both 17- and 13-year-olds (and attitude to teacher was not measured among 9-year-olds).

Some caution needs to be exercised in interpreting these finding for instructional quality, however, because the present study's two measures of quality (namely, science teaching budget and attitude to teacher) are not ideal indicators of quality of instruction. Consequently, the use of other indicators of instructional quality and variation - such as those identified as reasonably strong correlates of achievement in Walberg's (1984a) study - could provide stronger links between instructional quality and student achievement.

Quantity of instruction. It is salient that either or both of the variables measuring quantity of instruction - namely, the amount of science studied at school and the amount of homework - turned out to be significant independent predictors of outcomes among 17- and 13-year-olds, but not among 9-year-olds. In fact, amount of science was a significant independent predictor of science achievement and the amount of homework was a significant independent predictor of both science achievement and attitudes among 17- and 13-year-olds.

The simple correlation (not reported in this paper) between science achievement and the number of semesters of science taken by students in the 17-year-old sample was found to be 0.31. This is comparable to the correlation of 0.38 between achievement and instructional time in Frederick's synthesis (Frederick, 1980; Frederick & Walberg, 1980), although it is considerably lower than the correlation of 0.73 between mathematics achievement and the number of semesters of mathematics instruction found among a sample of 17-year-olds involved in the 1977-78 NAEP assessment in mathematics (Welch, Anderson, & Harris, 1982). In the present study, an increase among 17-year-olds of one semester in the amount of science taken was associated with an increase of only 0.57 of a point on the science achievement tes[illegible] other factors were held constant. One possible explanation for the low correlation between quantity of instruction and science achievement, relative to that for, mathematics achievement, is that there are more opportunities for learning science out of school than for mathematics (e.g., through zoos, museums, television, and magazines). On the other hand, amount of homework was a strong independent predictor for 17-year-olds so that an increase of one hour of homework per night was associated with an increase of over three points (over one-third of a standard deviation) on the science achievement measure and of over four points (about half of a standard deviation) in science attitude scores. (In other words, a 17-year-old student at the 50th percentile on achievement could improve to the 65th percentile through increasing homework by one hour per night.). Furthermore, the results for 13-year-olds' homework in Table IV are reasonably comparable in terms of numbers of standard deviations with the results for the 17-year-old sample.

<u>Class environment</u>. It is noteworthy that the nature of the classroom psychosocial environment emerged as a significant predictor of both science achievement and attitudes to science at all three age levels when other factors were held constant. These findings replicate individual studies of the effects of classroom environment on science achievement

and attitude (Fraser & Fisher, 1982), and are consistent with Haertel, Walberg, and Haertel's (1981) meta-analysis and Fraser's (1985) recent comprehensive review.

Home environment. Table IV shows that home environment was significantly related to science achievement at all three age levels when other factors were fixed. On the other hand, Table IV shows that home environment was a significant independent predictor of science attitude for the 17-year-old sample only. The simple correlations between home environment and cognitive achievement (not reported here) were somewhat weaker than in some past research, possibly due to the fact that home environment was assessed in terms of parental education and not directly in terms of measures of intellectual stimulation by adults in the home which have been found to correlate 0.37 on average with achievement (Graue, Weinstein & Walberg, 1983; Iverson & Walberg, 1982).

Television viewing. The results in Tables IV suggest that the amount of television viewing was significantly and negatively related to science achievement at all three age levels and to science attitude among 13-year-olds when other predictors were held constant. The negative relationship between science achievement and amount of television viewing at different ages is generally consistent with the negative correlation found at different age levels in a variety of content areas in a meta-analysis of 274 correlations from 23 studies, surveys, or reviews (Williams, Haertel, Haertel & Walberg, 1982). It is interesting to note from this meta-analysis, however, that the negative relationship between television viewing and achievement was stronger for boys than girls and was evident only in the range between 2 and 8 hours per day (so that a deleterious effect was not evident under 2 hours per day and increasing viewing beyond 8 hours had no additional negative effect). The beta weights in Table IV suggest that a one-hour decrease in television viewing per day is associated with an increase on the achievement test of 0.16 points for 17-year-olds, 0.09 for 13-year-olds, and 0.10 for 9-year-olds.

Gender. Prior research generally has revealed gender differences in both science achievement and science attitudes, with boys scoring higher than girls on both criteria (Gardner, 1974; Keeves, 1973). The results of the present research in Table IV indicate that these gender differences were replicated for science achievement at each of the three age levels. However, gender differences in science attitudes did not emerge at any of the age levels as significant predictors when other factors were controlled (see Table IV). Because gender is a binary variable coded 1 (male) and 0 (female), regression weights can be interpreted directly as group differences. Table IV shows that, on the science achievement test, boys outscored girls by 2.30 points at age 17, by 1.56 points at age 13, and by 0.74 points at age 9.

Race. Table IV shows that race was a significant independent predictor of science achievement for all these age groups, but was significantly related to science attitude only among 9-year-olds. The interpretation of these results for the binary coded race variable is that the science achievement of whites was superior to that of non-whites by 4.88 points (oven half a standard deviation) among 17-year-olds, by 4.13 points (almost two-thirds of a standard deviation) among 13-year olds, and by 2.60 points (over half a standard deviation) among

9-year-olds. On the attitude criterion, significant differences emerged only among 9-year-olds; whites scored 1.96 points (almost a third of a standard deviation) higher than non-whites.

CONCLUSION AND DISCUSSION

The results for the three age groups show that a number of factors, previously revealed to be consistent correlates of achievement in syntheses of small-scale bivariate research, were found also to be significant predictors of science students' achievement and attitude when mutually controlled for each other in a large national survey. This suggests that national achievement and attitudes are jointly influenced by a number of factors rather than by a single dominant one. The secondary analyses reported in this paper generally support the validity of Walberg's model of educational productivity, which involves nine factors which predict student learning. In the present research which involved at least one measure of seven of these productivity factors - namely, ability, motivation, quality of instruction, quantity of instruction, class environment, home environment, and the mass media environment - it is noteworthy that each of the seven factors emerged as a statistically significant predictor of both science achievement and science attitude at one or more of the three age levels when other factors were held constant. Among these seven factors, ability, motivation, and class environment were the most consistent predictors of student outcomes as they were significant independent predictors of both science achievement and attitudes at all three age levels. However, that the two variables of gender and race also emerged as significantly related to cognitive achievement at all age levels, as well as race being a predictor of attitude among 9-year-olds when all other factors were held fixed. These findings, if replicated in other studies, would suggest that the two variables of gender and race omitted from the original productivity model could be included in the model to improve the prediction of achievement in the area of science.

The present research has identified four relatively unalterable factors - namely, ability, home environment, gender, and race - which are significant independent predictors of science achievement and attitude at one or more of the three age levels. Still, five relatively school-alterable factors were significant independent predictors of science achievement and attitudes among at least one age group. These alterable factors are motivation, quality of instruction (indexed by science teaching budget per pupil and/or attitude to the teacher), quantity of instruction (assessed in terms of amount of science and/or amount of time devoted to homework), the class environment, and the amount of television viewing (negative relationship). It is encouraging to find that the present results suggest that there are numerous school-alterable factors which teachers can work on if they wish to improve the achievements and attitudes of their science students.

This paper attests to the potential usefulness of secondary analyses of data from large-scale assessments (Boruch, 1978; Bowering, 1984; Fraser & Tobin 1985). Clearly, there were important advantages in using the National Assessment in Science data base in the present study when compared with collecting primary data to investigate the same questions. These include the reduction in response burden on students and schools, the low cost of data, the quality of the large, national, random sample, and the possibility of future replications. (The data tape for the National Assessment in Science is readily available together with documentation at a cost of $125.) But also there are potential disadvantages facing secondary analysts of large-scale data bases. These include limitations imposed by the quality of the primary data, the problem that the data base may not contain good measures of the variables of interest, and difficulties in understanding and using the data because of its complexity or inadequate documentation. Fortunately, however, many of these potential problems have been overcome with the National Assessment in Science data because of thorough documentation, careful sampling and test administration, and use of a variety of quality checks at every stage of assessment and analysis.

The findings emerging from the present analyses refute several claims made in relation to school learning and assumptions made in educational research. First, although much prior research has been bivariate in nature, this study clearly illustrates that no single factor alone can produce marked increases in learning. Improving all the productive factors using scarce resources, including human time and effort, as efficiently as possible would seem a more advisable policy than improving only one. Second, the results are at variance with another commonly held view that school learning is too complex to be understood in terms of a relatively small number of underlying factors. The third notion dispelled by the present findings is that the only important factors in predicting student outcomes are those that cannot be altered by teachers or the school.

APPENDIX A

Descriptions and Operational Definitions of Variables

For Age 9

Achievement Outcome

29 multiple-choice items covering science content topics (e.g., evaporation, speed, light, germs), inquiry skills (including interpretation of data and tables, experimentation, use of controls), and an appreciation and understanding of societal issues (including health, nutrition, first aid, persistent world problems, use of computers). Maximum score = 29. Alpha reliability = 0.79.

Attitude Outcome

23 Likert-type items assessing students' opinions about the usefulness and value of science, attitudes toward science careers, and willingness to solve social problems (e.g., by using less electricity and heating). Each item is responded to on a three-point scale. Most items are scored:

1 = No
2 = I don't know
3 = Yes

Some items are scored in the reverse manner. Range = 23-69. Alpha reliability = 0.69.

Ability

5 multiple-choice items assessing classification and mapping abilities. Alpha reliability = 0.61.

Motivation

Mean of 21 items assessing whether students have ever been involved in a variety of science-related activities and experiments (e.g., working with magnets, seeds, microscopes, thermometers, batteries).

Range = 21-63. Alpha reliability = 0.71. Each item is scored:

1 = No
2 = I don't know
3 = Yes

Science Teaching Budget

Science teaching budget in dollars per student obtained from a principal's questionnaire requesting information on the school's total instructional budget, the percentage devoted to science, and the number of students in the school.

Hours of Science

An item on the principal's questionnaire requesting information on the number of hours per week, averaged across Grades 3 and 4, for which science is taught. Coded as:

0 = Less than 0.5 hours per week
1 = 0.5-1.5 hours per week
2 = 1.5-2.5 hours per week
3 = More than 2.5 hours per week

Homework

An item asking students to indicate the average amount of time per day spent on homework (all school subjects). Coded as:

0 = None
1 = Less than 1 hour per day
2 = Between 1 and 2 hours per day
3 = More than 2 hours per day

Class Environment

The mean of 5 items asking students if science classes usually made them feel "happy", "interested", "dumb" (reverse scoring), "excited", and "successful". Alpha reliability = 0.60. Except for the items with reverse scoring, coding is:

1 = No
2 = I don't know
3 = Yes

Home Environment

The higher of the ratings for father's and mother's education coded as:

1 = Did not complete 8th grade
2 = Completed 8th grade, but did not go to high school
3 = Went to high school, but did not graduate from high school
4 = Graduated from high school
5 = Some education after graduation from high school
6 = Graduated from college

Television Viewing

An item asking students how many hours of TV they watched during the previous day. Coded as:

1 = Watched 1 hour or less
2 = 2 hours
3 = 3 hours
4 = 4 hours
5 = 5 hours
6 = 6 hours or more

Gender

Coded as:

1 = Male
0 = Female

Race

Student-reported racial background with blacks, native Americans, hispanics and asians included in the non-white category. Where inconsistencies existed in the student responses to two questions about race, responses were recorded as "other" and included in the non-white category. Coded as:

1 = White
0 = Non-white

APPENDIX B

Descriptions and Operational Definitions of Variables for Ages 13 and 17

Achievement Outcome

49 multiple-choice items covering science content topics (e.g., energy, life, changing aspects of the earth), inquiry skills (including experimentation, data interpretation, measurement, problem definition, and solution), understanding of the role of theories in science, and an appreciation and understanding of societal issues (including health, resource management, nutrition, safety, and the costs and benefits associated with applied science and technology). Maximum score = 49. Alpha reliability = 0.87 for 17-year-olds and 0.80 for 13-year-olds.

Attitude Outcome

19 Likert-type items assessing students' opinions about the usefulness and value of science and willingness to solve social problems (e.g., by turning off lights when they are no longer needed). Alpha reliability = 0.72 for 17-year-olds and 0.68 for 13-year-olds. Each item is responded to on a five-point scale. Some items are scored in the opposite direction. Maximum score = 95. Except for items with reverse polarity, items are coded as:

5 = Always or Strongly agree or Definitely yes
4 = Often or Agree or Probably yes
3 = Sometimes or No opinion or No response
2 = Seldom or Disagree or Probably not
1 = Never or Strongly disagree or Definitely not

Ability

A self-report item asking students to describe grades in school so far coded as:

8 = Mostly A
7 = About half A and half B
6 = Mostly B
5 = About half B and half C
4 = Mostly C
3 = About half C and half D
2 = Mostly D
1 = Mostly below D

Motivation

The mean of 8 items asking how often science-related activities (e.g., reading science articles in magazines, watching science shows on TV, going to hear people give talks on science) have been done when not required for science classes. Alpha reliability = 0.82 for 17-year-olds and 0.78 for 13-year-olds. Coded as:

5 = Often
4 = Sometimes
3 = No opinion or No response
2 = Seldom
1 = Never

Science Teaching Budget

Science teaching budget in dollars per student obtained from a principal's questionnaire reporting the school's total instructional budget, the percentage devoted to science, and the number of students in the school.

Attitude to Teacher

The mean of 5 Likert-type items requesting students' opinion about their present or most recent science teacher. The items ask whether the teacher "really likes science", "wants students to point out mistakes...", "makes science exciting", "is enthusiastic", and "is willing to share opinions..." Alpha reliability = 0.72 for 17-year-olds and 0.66 for 13-year-olds. Coded as:

5 = Strongly agree
4 = Agree
3 = No opinion
2 = Disagree
1 = Strongly disagree

9-year olds. This variable was not assessed with the 9-year-old sample.

Quantity of Science Instruction

17-year-olds. An item requesting students to indicate for how many semesters (2, 1 or less than 1) they had studied each specific science course (general science, life science, biology, health, environmental science, chemistry, physical science, physics, earth science, geology, other) in the 9th, 10th, 11th, and 12th grades. This variable is defined as the sum of the number of semesters of each type of science course. Range is 0-8.

13-year-olds. Based on two items asking students if they are taking a science course currently and whether they were taking one at the same time during the previous year. Coded as:

0 = Taking a science course in neither years
1 = Taking a science course in one of the years
2 = Taking a science course in both years

Homework

An item asking students to indicate the average amount of time per day spent on homework (all school subjects). Coded as:

0 = None
1 = Less than 1 hour per day
2 = Between 1 and 2 hours per day
3 = More than 2 hours per day

Class Environment

The mean of 6 items asking students if science classes made them feel "uncomfortable" (reverse scoring), "curious", "stupid" (reverse scoring), "confident", "successful", and "unhappy" (reverse scoring). Alpha reliability = 0.78 for 17-year-olds and 0.68 for 13-year-olds. Except for items with reverse scoring, coding is:

1 = Never
2 = Seldom
3 = Sometimes
4 = Often
5 = Always

Home Environment

The higher of the ratings for father's and mother's education coded as:

1 = Did not complete 8th grade
2 = Completed 8th grade, but did not go to high school
3 = Went to high school, but did not graduate from high school
4 = Graduated from high school
5 = Some education after graduation from high school
6 = Graduated from college

Television Viewing

An item asking students how many hours of TV they watched during the previous day. Coded as:

1 = Watched 1 hour or less
2 = 2 hours
3 = 3 hours
4 = 4 hours
5 = 5 hours
6 = 6 hours or more

Gender

Coded as:

1 = Male
0 = Female

Race

Racial background with blacks, native Americans, hispanics and asians included in the non-white category. Coded as:

1 = White
0 = Non-white

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TABLE I

Number of Items, Mean, Standard Deviation, and Intercorrelations for Learning Measures and Productivity Factors (N=1,960)

Variable	No. of Items	Mean	SD	Intercorrelations*											
				Achievement	Attitude	Ability	Motivation	Budget	Hours of Sci.	Homework	Class Env.	Home Env.	TV	Gender	Race
Outcomes															
Achievement	29	16.13	5.07	-											
Attitude	23	57.62	6.34	45	-										
Ability	5	2.90	1.43	48	25	-									
Motivation	21	2.28	0.34	25	31	14	-								
Quality of Instruction															
Science teaching budget	1	3.21	3.36	01	04	04	06	-							
Quantity of Instruction															
Hours of science/week	1	1.43	0.82	00	03	00	-02	-15	-						
Homework	1	1.21	0.80	03	03	08	01	-05	06	-					
Class Environment	5	2.45	0.50	14	36	04	16	-04	06	03	-				
Home Environment	1	5.11	1.07	16	09	13	11	00	01	01	02	-			
Television Viewing	1	3.06	2.37	-10	-06	-03	03	00	-10	-04	-05	-04	-		
Gender	1	0.51	0.50	06	03	-06	09	02	-04	-05	00	03	09	-	
Race (white, non white)	1	0.79	0.41	31	17	19	-11	11	-06	-02	-03	05	-13	00	-

*Decimal points have been omitted.

TABLE II

Raw Regression Weights and t Ratios for Full and Reduced Model of Productivity Factors (N=1,960)

Productivity Factor	Statistic	Achievement Full	Achievement Reduced	Attitude Full	Attitude Reduced
Ability	b	1.44	1.43	0.69	0.70
	t	21.04*	21.07*	7.63*	7.89*
Motivation	b	2.22	2.19	4.08	4.16
	t	7.72*	7.63*	10.73*	11.04*
Quality of Instruction					
Science teaching budget	b	-0.05		0.03	
	t	-1.73		0.81	
Quantity of Instruction					
Hours of science/week	b	0.02		0.20	
	t	0.23		1.28	
Homework	b	-0.03		0.02	
	t	-0.24		0.12	
Class Environment	b	0.20	0.20	0.82	0.82
	t	5.04*	5.13*	15.93*	16.12*
Home Environment	b	0.33	0.33	0.18	
	t	3.65*	3.68*	1.56	
Television Viewing	b	-0.13	-0.13	-0.07	
	t	-3.16*	-3.22*	-1.32	
Gender	b	0.74	0.74	0.28	
	t	3.90*	3.88*	1.12	
Race (white/non-white)	b	2.60	2.56	1.96	2.02
	t	10.91*	10.81*	6.19*	6.51*
Multiple Correlation :		0.57	0.57	0.50	0.49

* $p<0.01$

TABLE III

Number of Items, Alpha Reliability (Where Appropriate), Mean, and Standard Deviation for all Achievement Measures and Productivity Factors for 17-Year-Olds (N = 1,955) and 13-Year-Olds (N = 2,025)

Variable	17-Year-Olds				13-Year-Olds			
	No. of Items	Alpha Relia-bility	Mean	SD	No. of Items	Alpha Relia-bility	Mean	SD
Outcomes								
Achievement	49	0.87	33.20	8.04	49	0.80	28.56	6.84
Attitude	19	0.72	68.75	7.90	19	0.68	66.27	8.19
Ability	1	-	5.44	1.54	1	-	5.80	1.60
Motivation	8	0.82	2.59	0.88	8	0.78	2.70	0.88
Quality of Instruction								
Science teaching budget	1	-	5.75	5.70	1	-	4.91	8.86
Attitude to teacher	5	0.72	3.70	0.71	5	0.66	3.64	0.68
Quantity of Instruction								
Amount of science	1		3.70	1.78	1	-	1.63	0.64
Homework	1		1.39	0.82	1	-	1.53	0.76
Class Environment	6	0.78	3.33	0.71	6	0.68	3.40	0.67
Home Environment	1	-	4.66	1.12	1		4.88	1.11
Television Viewing	1		1.80	2.07	1		2.80	2.09
Gender	1		0.47	0.50	1		0.48	0.50
Race (white, non-white)	1	-	0.81	0.39	1		0.79	0.40

TABLE IV

Comparison of Raw Regression Weight for Each Productivity Factor for Three Age Levels for Science Achievement and Science Attitude

Productivity Factor	Regression Weight for Achievement			Regression Weight for Attitude		
	Age 17	Age 13	Age 9	Age 17	Age 13	Age 9
Ability	1.49**	0.81**	1.44**	0.52**	0.38**	0.69**
Motivation	1.04**	1.09**	2.22**	3.02**	2.51**	4.08**
Quality of Instruction						
Science teaching budget	0.06*	0.04*	-0.05	0.03	0.01	0.03
Attitude to teacher	0.55*	0.00		1.24**	2.16**	-
Quantity of Instruction						
Amount of science	0.57**	1.66**	0.02	-0.06	-0.31	0.20
Homework	3.11**	2.05*	-0.03	4.06**	4.30**	0.02
Class Environment	0.66**	1.14**	0.20**	1.23**	1.70**	0.82**
Home Environment	0.83**	0.51**	0.33**	0.48**	0.17	0.18
Television Viewing	-0.23**	-0.17**	-0.13**	-0.01	-0.21*	-0.07
Gender	2.30**	1.56**	0.74**	-0.60	-0.16	0.28
Race	4.88**	4.12**	2.60**	-0.55	-0.10	1.96**
Multiple Correlation:	0.59**	0.50**	0.57**	0.52**	0.51**	0.50**

* p<0.05, ** p<0.01

Sample consisted of 1,955 17-year-olds, 2,025 13-year-olds and 1,960 9-year olds.