Probability-Makers for Student Success: A Multilevel Logistic Regression Model of Meeting the State Learning Standards

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Paper presented at the Annual Meeting of the New England Educational Research Organization, Portsmouth, NH
April 2006

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All civilizations try to convey knowledge, skills, and practices from one generation to the next. Students, families, educators, government officials, and others struggle with the question of how best to do so, given that resources are always scarce. Some think, often erroneously, that they already know the answer. In Maine and other states, much debate and some action has been directed toward helping all children meet state learning standards while, at the same time, not overspending. Federal and state governments as well as schools, students, and families may play a role in improving or impairing education. Some potential reforms, e.g., regionalizing central office functions, may save money. But will they impair student learning? Other potential reforms, e.g., building small schools or decreasing pupil-teacher ratios, may cost money. But will they really help students learn? Still others, e.g., doing more homework, may neither cost money nor save money. But do they have a chance to make a difference?

The purpose of this study was to determine what, or part of what, makes academic success probable or improbable for a student. The core research question was, Which practices, characteristics, and circumstances of students, families, schools, school districts, and communities tend to give Maine students a higher probability of meeting state learning standards? Multilevel logistic linear modeling was used in answering the core research question. A multilevel analysis method was chosen to reflect the hierarchal nature of the education system—students belong within schools, which themselves belong within school districts—and to allow conclusions to be drawn regarding the characteristics and practices at each of these levels. Logistic models were chosen so that results could be interpreted in terms of the probability of success rather than, say, point scores on a test.

Similar studies (such as Lee and Bryk, 1989; Willms and Somer, 2001; Lee and Smith, 1997; and Ma, 2000) have focused on academic achievement as a matter of degree, using scale scores on standardized exams as a measure of relative success. These studies unquestionably provide valuable information. However, given the goal of having every student meet a particular learning standard, it is also important to have information concerning student success as a dichotomous measure. Decision makers—including students, parents, teachers, administrators, and government officials—are concerned with meeting absolute standards such as the Maine Learning Results, and with not leaving any children behind or, from the student perspective, with not being left behind. This study, due to its focus on the probability of meeting a standard of success, will address these concerns directly.

Literature Summary

Multilevel models have been used in education research in several ways. Lee and Bryk (1989) provide a classic example of multilevel modeling in education by attempting to identify characteristics of high schools that are associated with a high level of student academic achievement and with an equitable distribution of achievement across socioeconomic status, race or ethnicity, and student academic background. Only one variable—an indicator variable for Catholic schools—was found to be associated with both higher school mean achievement and smaller achievement gaps. Other variables, including school average socioeconomic status and the absence of staff problems, were associated with higher achievement but also with larger achievement gaps.

Willms and Somer (2001) provide a similar analysis of 3rd and 4th grade achievement in each of 13 Latin American countries. They found that in all 13 countries, girls scored higher than boys in language and lower in mathematics, fourth graders scored higher than third graders, and that parental education levels and the presence of ten or more books in the home were significant predictors of student success. At the school level, significant predictors included regular testing, strong parental involvement, positive classroom climate, single-grade classrooms, not using ability grouping, teacher training, size of library, and the quantity and availability of instructional materials.

Multilevel modeling can also be used to test for the presence of an association between outcomes and a single independent variable of interest, as was done by Lee and Smith (1997), who investigated the relationship between high school size and student academic achievement. They found that the ideal high school size for achievement is between 600 and 900 students, that achievement gaps are smallest for the smallest schools, and that the school size effect is stronger for minority and low socioeconomic status students.

More specialized questions are also answerable using multilevel modeling, such as the questions answered by Ma (2000), who examined socioeconomic achievement gaps to determine if they are consistent across subject areas. He found moderate correlations among the school achievement gaps by subject area. He also found, somewhat paradoxically, that the mathematics and science gaps were larger in schools with extensive parental involvement. He did not note, however, whether mean science and mathematics achievement were higher or lower in schools with extensive parental involvement.

Another strategy for discovering the characteristics of successful schools involves mixed methods, where quantitative methods are used to identify successful schools, and then sight visits with observations and interviews are used to determine the common characteristics of the successful schools. Examples of this method include McCallum (1999), who studied schools in England; McGee (2004), who studied schools in Illinois, excluding Chicago; Mosenthal, Lipson, Torncello, Russ, and Mekkelsen (2004), who studied schools in Vermont; and Silvernail (2004), who studied schools in Maine. Whereas three of these studies were in largely rural areas, only one of the multilevel modeling studies mentioned above (Ma, 2000) studied schools in a rural area, in this case New Brunswick, Canada.

METHODOLOGY

Data Analysis

The data were analyzed using multilevel logistic regression. Multilevel, or hierarchical, linear regression is like ordinary least squares regression, except that instead of choosing a single unit of analysis, such as the student or the school, one chooses two or three units of analysis, such as the student *and* the school, related such that the units at one level of analysis belong to the units at the next, as students belong to schools. Models are constructed at each level, and are interrelated in that the coefficients at the lower levels are treated as outcomes at the next higher level. Student success was the outcome variable at the student level. The school success *rate* was the outcome variable at the school level, but it also acts as the constant in the model at the student level.

Because the outcome variable at the student level was a dichotomous measure of student success, in accordance with standard practice, logistic modeling was used. In a logistic model, the predicted values of the regression are not compared directly to the outcome variable as in OLS regression. Rather, each predicted value is treated as the logit (i.e., logarithm of the odds ratio) of a positive outcome. That is, if $\hat{Y}$ is a predicted value from the regression and p is the probability of a positive outcome, $\hat{Y} = \log_e [p / (1 - p)]$. Predicted values are easily converted to probabilities, p. Specifically, $p = [1 / (1 + e^{-\hat{Y}})]$. The predicted value, qua logit, can be any finite positive or negative number, but the probability corresponding to it will always be between zero and one.

Levels and Units of Analysis

The primary units of analysis were students, schools, and school districts. A single model was produced that included all 4^{th}, 8^{th}, and 11^{th} graders in Maine. This could allow school districts to be evaluated as a whole, which would be impossible in the single-grade models, since districts contain more than one grade. It would also provide a foundation for direct tests of differences in the probability relations between success and other variables for different grade levels. The model for this study comprised the following three levels:

- Level 1: Students and their families,
- Level 2: Schools and their grade levels, and
- Level 3: School districts and their communities.

Most schools include only one of the grades being studied, 4^{th}, 8^{th}, and 11^{th}. Those few that contain more than one of these grades were represented as more than one entity at Level 2.

Variables

Each level in each model contained outcome variables and predictors. At the lowest level, the outcome variable was a success indicator. At higher levels, outcomes included both success rates and proficiency gaps, such as the gap in a particular school between the success rates of minority and non-minority students. The variables and their descriptions are listed in Table 1a and Table 1b.

Outcome Variables. The outcome variables at the student level were defined in terms of proficiency levels on the Maine Education Assessment (MEA) for 4^{th}, 8^{th}, and 11^{th} grades in the subject areas of reading, writing, and mathematics. There are four proficiency levels for each subject area: Does Not Meet, Partially Meets, Meets, and Exceeds. Success in a particular subject area was defined as achieving a proficiency level of Meets or Exceeds. A student was considered successful if she achieved a Meets or Exceeds proficiency level in all three subject areas.

Table 1a: Student Variables

Student Variable	Student Level	School Level	District Level	Description	Source
Success	binary	rate	rate	Student meets or exceeds state proficiency standards in reading, writing, and mathematics, as measured by the MEA	MEA
Gender	binary	rate	rate	Female or male	MEA
Race/Ethnicity	binary	rate	rate	Student is a member of a racial or ethnic minority group	MEA
LEP	binary	rate	rate	Student is identified as having limited English proficiency	MEA
Special Education	binary	rate	rate	Student receives special education services	MEA
Economically Disadvantaged	binary	rate	rate	Student is eligible for the National Student Lunch Program	MEA
Homework: One Hour or More	binary	rate	rate	Student reports spending at least one hour doing homework each day	MEA
Homework: None	binary	rate	rate	Student reports doing no homework on school nights	MEA
Read at Home: 20 Minutes or More	binary	rate	rate	Student reports spending at least twenty minutes reading at home each day	MEA
Read at Home: Rarely or Never	binary	rate	rate	Student reports rarely or never reading at home	MEA
Use Computer for Writing: Rarely or Never	binary	rate	rate	Student reports rarely of never using a computer to work on writing	MEA
Search For and Read Information on Computer in English Language Arts: Almost Every Day	binary	rate	rate	Student reports searching for and reading information in on a computer English Language Arts almost every day	MEA
Search For and Read Information on Computer in English Language Arts: Rarely or Never	binary	rate	rate	Student reports rarely or never searching for and reading information in on a computer English Language Arts	MEA

Table 1b: Student Variables

School Variable	School Level	District Level	Description	Source
Grade 4	binary	rate	School's test results are grade 4 MEA	MEA
Grade 8	binary	rate	School's test results are grade 8 MEA	MEA
Grade 11	binary	rate	School's test results are grade 11 MEA	MEA
Learning Matches MEA Test: Reading	rate	mean	Proportion of students reporting that what they learn in school in reading matches what is tested on the MEA	MEA
Learning Matches MEA Test: Mathematics	rate	mean	Proportion of students reporting that what they learn in school in mathematics matches what is tested on the MEA	MEA
School Variable	**School Level**	**District Level**	**Description**	**Source**
Median Home Value	-	dollar value	The value of the median-valued home, as reported by the U.S. Census	NCES
Proportion of Population in Urbanized Areas	-	rate	As reported by the U.S. Census	NCES
Proportion of Population in Urban Clusters	-	rate	As reported by the U.S. Census	NCES
District Size	-	total	Attending Enrollment	MDOE
Mean School Size	-	mean	Attending Enrollment	MDOE
Per-Pupil Operating Expenditure	-	dollar value	Operating expenditure divided by district enrollment	MDOE
Pupil/Teacher Ratio	-	ratio	The full-time-equivalent (FTE) number of teachers divided by the total enrollment	MDOE
Teacher Education	-	rate	Proportion of teachers having a masters or other advanced degree	MDOE
Teacher Experience	-	mean	The mean number of years teaching	MDOE

Predictor variables. Predictor variables at the student level were student demographic variables such as sex, race, special education status, parental education, and socioeconomic status (defined by participation in federal lunch subsidy programs) along with answers to questions on the MEA student questionnaire. Predictors at the school level were of three basic types:

compositional variables, i.e., aggregates of student level variables, such as the percentage of students receiving free or reduced-priced lunches; context variables, i.e., other variables largely beyond the control of the school, such as school enrollment; and climate variables, i.e., those largely within the control of the school and its members, such as the amount of homework assigned. School and school district predictor variables included demographic, enrollment, financial, and staffing variables from the Maine State Department of Education (MDOE), and community information from the 2000 U.S. Census.

Student-level predictors. Predictors of success at the student level included variables in the categories of family context, student characteristics and student practices, and are described in Table 1. Family context and student characteristics consisted of variables that are largely beyond the control of the student. Student practice variables are more or less within the control of the student.

School-level predictors. Predictors of success at the school level included variables in the categories of school context, school climate, and school practices, and are described in Table 2. School context variables are largely beyond the control of school employees and students. School climate and school practice are more or less within the control of school employees and students.

District-level predictors. Predictors of success at the school district level included variables in the categories of community context, district context, and district practices, and are described in Table 3. Community context variables are beyond the control of school district and municipal officials. District practice is more or less within the control of school district or municipal officials. District context is at most indirectly under the control of school district officials.

Data Sources. Student data came from the Maine Education Assessment, including proficiency levels by subject area, demographic variables, and student responses to a survey appended to the assessment. School enrollment, staff data, and completion rates came from the Maine State

Department of Education, and were derived from reports by school districts filed with the state. District expenditures, staff data, and per-pupil valuations were provided by the Maine State Department of Education. Community context variables were obtained from the National Center for Education Statistics (NCES), and were derived from U.S Census data.

Building the Model

Starting with a bare model, where all variation is relegated to the error terms at each level, the model was built level by level. Student variables were added as predictors of student success. Once a satisfactory model of student success was established, school variables along with aggregated student variables, such as the percentage of students receiving special education services, were added as predictors of school success rates. Finally, district variables, along with aggregated student and school variables were added as predictors of district success rates. The result is known as a means-as-outcomes model, because the mean of the student-level success variable (i.e., the success rate) is treated as an outcome at the school level, and the mean of the school success rates is treated as an outcome at the district level.

RESULTS

In all, the data consisted of records for 44,975 students in 618 schools in 218 districts. Descriptive statistics are presented in Table 2.

Table 2. Descriptive Statistics

Student Variables	Mean	Standard Deviation*
Success	0.13	-
Gender: Male	0.51	-
Race/Ethnicity: Minority	0.05	-
LEP	0.01	-
Special Education	0.15	-
Economically Disadvantaged	0.30	-
Homework: One Hour or More	0.38	-
Homework: None	0.08	-
Read at Home: 20 Minutes or More	0.57	-
Read at Home: Rarely or Never	0.23	-
Use Computer for Writing: Rarely or Never	0.21	-
Search For and Read Information on Computer in English Language Arts: Almost Every Day	0.08	-
Search For and Read Information on Computer in English Language Arts: Rarely or Never	0.33	-
School Variables	**Mean**	**Standard Deviation***
Grade 4	0.51	-
Grade 8	0.32	-
Grade 11	0.18	-
Learning Matches MEA Test: Reading	0.22	0.15
Learning Matches MEA Test: Mathematics	0.31	0.17
District Variables	**Mean**	**Standard Deviation**
Median Home Value (in $Thousands)	95.7	37.8
Proportion of Population in Urbanized Areas	0.09	0.24
Proportion of Population in Urban Clusters	0.09	0.21
District Size (Attending Enrollment)	908.3	1,090.9
Mean School Size (Attending Enrollment)	251.3	152.5
Per-Pupil Operating Expenditure ($Thousands)	7.1	2.1
Pupil/Teacher Ratio	12.8	2.6
Teacher Education (Proportion Masters or More)	0.32	0.18
Teacher Experience(Years)	16.4	3.6

*Standard deviations are not shown for binary variables. For binary variables, SD = $\sqrt{M (1 - M)}$.

Several variables at each level of analysis were found to have coefficients that are significantly positive or negative. At the student level, five significant family context and student characteristic variables were found: economic disadvantage, gender, ethnicity or race, limited English proficiency, and special education status. These are shown in Table 3. Aggregate rates of two of these variables—special education and economic disadvantage—were also significant in determining school and district success rates. Several practice variables were also found to be significant, also shown in Table 3, including time spent doing homework, time spent reading at home, and frequency of computer use for writing and for searching for and reading information.

Several school variables were also found to be significant, including grade level (4th, 8th, or 11th) and student perceptions of the match between what they learned in school and what was tested on the MEA in mathematics. These variables were found to be significant predictors of both schools mean and district mean success rates. The match between what students learned in school and what was tested on the MEA in reading was not found to be significant. Coefficients for school variables, as well as district variables, are shown in Table 4.

Three community and district context variables were found to be predictive of district success rates: median home value, being an urbanized area, and total district enrollment. Other variables tested, including school sizes, per-pupil expenditures, teacher education and experience, and pupil/teacher ratios, were not found to be significant predictors of student success.

In mathematical terms, the coefficients in a logistic analysis, such as this one, represent the difference in the logarithm of the odds ratio of success, given a one-unit change in the predictor variable. This is not a commonplace notion. However, for binary predictors, the coefficients are easily translated into differences in the probability of success. Due to the mathematics of logistic regression, the same coefficient makes less of a percentage-point difference for very high or very low probabilities than it does for probabilities around 50%.

But if we pick a base probability, such as the probability for a student of average characteristics in an average school, around which to calculate our probability differences, the results allow a reasonably simple interpretation. Table 5 lists the student level predictor variables, all of which are binary, together with the estimated probability of success for each group identified by the variable. For instance, in the absence of any information about a student or the student's school, on the basis of this model one would estimate that the probability of the student achieving the state learning standard is around 9.3% if the student is a girl or 7.0% if the student is a boy, making for a 2.3% difference in the probability of success on account of gender.

The model is additive. If a student were to have all of the advantageous family context variables and student characteristics, all the coefficients for those variables would contribute to that student's probability of success. Thus, a white, non-Hispanic girl, who does not receive special education services, is not eligible for free or reduced lunches, and whose first language is English, if we knew nothing more about her, would have a 17.1% probability of success, according to the model. If we also knew she also did one or more hour of homework per day, read at home for at least 20 minutes a day, used a computer to work on her writing, and rarely used a computer to search for and read information in English language arts class, the probability would jump to 28.9%. However, if we knew she did no homework, rarely read at home, never used a computer to work on her writing and searched for and read information using a computer in English language arts class almost every day, her probability of success would be only 2.9%.

Table 3. Multilevel Model of Student Success, Part 1:
Student Variables and Their School and District Level Aggregates

Variable	Student Level Coefficient (t ratio)	School/Grade Level Coefficient (t ratio)	District Level Coefficient (t ratio)
Constant	**-2.432***** (-37.845)	-	-
Gender: Male	**-0.309***** (-9.910)	-	-
Race/Ethnicity: Minority	**-0.214***** (-2.689)	-	-
LEP	**-1.323***** (-4.310)	-	-
Special Education	**-2.599***** (-20.413)	**-1.245**** (-2.993)	**-2.382***** (-3.903)
Economically Disadvantaged	**-0.945***** (-19.949)	**0.549*** (2.420)	**0.835***** (2.984)
Homework: One Hour or More	**0.284***** (8.438)	0.384 (1.456)	0.326 (0.724)
Homework: None	**-0.402***** (-4.775)	-	-
Read at Home: 20 Minutes or More	**0.360***** (8.516)	0.146 (0.511)	0.098 (0.219)
Read at Home: Rarely or Never	**-0.477***** (-8.558)		-
Use Computer for Writing: Rarely or Never	**-0.449***** (-8.594)	-0.097 (-0.385)	0.640 (1.304)
Search For and Read Information on Computer in English Language Arts: Almost Every Day	**-0.535***** (-7.729)	-0.589 (-1.074)	-0.569 (-0.759)
Search For and Read Information on Computer in English Language Arts: Rarely or Never	**0.102**** (2.905)	-0.090 (-0.358)	0.208 (0.486)

* Significant at the 0.050 level
** Significant at the 0.010 level
*** Significant at the 0.001 level

Table 4. Multilevel of Student Success, Part 2:
School Variables, Their District Level Aggregates, and District Variables

Variable	School/Grade Level Coefficient (t ratio)	District Level Coefficient (t ratio)
Grade 8	**0.910***** (6.934)	**0.954*** (2.243)
Grade 11	**0.645***** (4.231)	**1.105**** (3.048)
Learning Matches MEA Test: Reading	-0.155 (-0.458)	0.895 (1.772)
Learning Matches MEA Test: Mathematics	**1.699***** (5.876)	**2.144***** (4.393)
Median Home Value (in $Thousands)	-	**0.009***** (4.868)
Proportion of Population in Urbanized Areas	-	**0.345**** (2.878)
District Size (Attending Enrollment - Thousands)	-	**-0.074*** (-2.158)
Mean School Size (Attending Enrollment - Thousands)	-	0.524 (1.392)
Per-Pupil Operating Expenditure (in $Thousands)	-	-0.024 (-0.518)
Pupil/Teacher Ratio	-	-0.058 (-1.908)
Teacher Education (Percent Masters or More)	-	-0.497 (-1.593)
Teacher Experience (Years)	-	0.002 (0.143)

* Significant at the 0.050 level
** Significant at the 0.010 level
*** Significant at the 0.001 level

Table 5. Coefficients of Student Level Variables
Converted to Differences in the Probability of Success

Variable	Group I	Group II	% in Group II	Estimated Odds of Success (All Else Equal and Average)		Estimated Probability of Success (All Else Equal and Average)		
				Group I	Group II	Group I	Group II	Difference
Constant	All Students			1 : 11		8.1%		-
Gender:	Girls	Boys	51%	1 : 10	1 : 13	9.3%	7.0%	-2.3%
Race/Ethnicity:	White, Not Hispanic	Minority	5%	1 : 11	1 : 14	8.2%	6.7%	-1.5%
LEP Status:	Not LEP	LEP	1%	1 : 11	1 : 42	8.2%	2.3%	-5.9%
Special Education Status:	No Special Education	Special Education	15%	1 : 8	1 : 104	11.5%	1.0%	-10.5%
Economic Status:	Not Economically Disadvantaged	Economically Disadvantaged	30%	1 : 9	1 : 22	10.4%	4.3%	-6.1%
Homework:	Less Than One Hour	One Hour or More	38%	1 : 13	1 : 10	7.3%	9.5%	2.2%
Homework:	Some	None	8%	1 : 11	1 : 16	8.3%	5.7%	-2.6%
Read at Home:	Less Than 20 Minutes a Day	At Least 20 Minutes a day	57%	1 : 14	1 : 10	6.7%	9.3%	2.6%
Read at Home:	More than Rarely	Rarely or Never	23%	1 : 10	1 : 16	8.9%	5.7%	-3.2%
Use Computer for Writing:	More than Rarely	Rarely or Never	21%	1 : 10	1 : 16	8.8%	5.8%	-3.0%
Search For and Read Information on Computer in English Language Arts:	Less Than Almost Every Day	Almost Every Day	8%	1 : 11	1 : 19	8.4%	5.1%	-3.3%
Search For and Read Information on Computer in English Language Arts:	More than Rarely	Rarely or Never	33%	1 : 12	1 : 11	7.8%	8.6%	0.8%

DISCUSSION

The results of this study add to the understanding of student success and, to the extent that the success of a school reduces to the success of its students, to the understanding of school success. They may help direct Maine citizens toward reforms that will help students meet the learning standards and, perhaps just as importantly, direct them away from potential reforms that, while being perhaps vigorously promoted or intuitively appealing, do not give students a better chance to meet the learning standards. The results may help guide students, families, and educators in the daily educational decisions they make.

Several caveats should be kept in mind while interpreting the results of this study. First, it may be tempting to equate the probability of success with the opportunity for success. A high probability of success does not, however, guarantee a good opportunity for success. A student may not have much opportunity for success, but because we do not know this, her probability of success might be high from our epistemic standpoint. Second, it is important to keep in mind the difference between causal relationships and probabilistic relationships. This study provides information about probabilistic relationships. One might say that it assesses the *news* value, but not necessarily the *instrumental* value, of the practices and characteristics studied. Absent the ability to make complete causal explanations and predictions of student success, such information may be invaluable.

The results provide some potentially useful information for students and for the families, teachers, and schools who are trying to help them to succeed. For instance, students who do at least one hour of homework a day, and those who read at home at for least 20 minutes a day, have a substantially higher probability of achieving the learning standards than students who do no homework or who rarely or never read at home. This should not be a surprise, but it should also not be disregarded. It may not mean that assigning more homework is useful. It may only mean that doing the homework assigned is important. Other significant student level predictor variables, such as gender and economic status, are beyond anybody's control. However, the variables that can be controlled may play a substantial role in reversing or mitigating the reductions in any student's probability of success.

The results pertaining to the school and district variables may have fewer practical implications. Beyond assuring that the mathematics that is taught in class matches the mathematics that is tested on the MEA, and that students can see that they match, there were few significant results. No evidence was found in this study that school size, expenditure, pupil/teacher ratios, teacher education or teacher experience generally make a difference in students' probability of success.

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