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ABSTRACT

The effects of class size on student achievement in science were studied using grade 8 science achievement mean scale scores for 138 Tennessee public school districts, focusing on the total population of districts and on districts in the upper and lower quartile of science performance (n=52). The dependent variable was district aggregate science achievement; the independent variables were percentage of classes that were at or below the state-mandated class size, district per pupil expenditure, and percentage of students qualified for free or reduced price meals. Results of regression analyses indicate that class size had a direct effect on student achievement, as did student poverty and per pupil expenditure. However, student poverty and per pupil expenditure also affected class size. The study shows the importance of taking both a macro and micro approach to the study of class size effects, as data show that many lower socioeconomic status (SES) schools were actually able to achieve at or above the levels of some high SES schools. However, the study provides evidence of the efficacy of class size as a correlate of student achievement in science at grade 8. (Contains 2 figures, 4 tables, and 17 references.) (SLD)

Class Size and Student Science Achievement: Not As Easy As It Sounds

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TVEE.ORG

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Invited Symposium
Making Sense of Class-size Research, Theory, and Use

Paper presented at the Annual Meeting
of the Mid-South Educational Research Association
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Class Size and Student Science Achievement: Not As Easy As It Sounds[1]

Background and Related Literature

The research and literature on class size has a rather lengthy history. Various class size models have evolved and been refined over time so that care must be taken when selecting and defining variables that the researcher will use when beginning a new study or when examining existing data. The present study will provide both a "macro" and "micro" view of class size within the context of student achievement as well as briefly addressing several nonachievement variables such as teachers' attitudes about class size. Although the class size research has existed to improve student achievement, many researchers and practitioners have examined nonachievement variables that may also affect student achievement. Among others, these include teacher morale, school climate, and more time for individualized instruction (Achilles, 1999). In 1979 Glass and Smith published findings of a meta-analysis using over a decade of research on class size and student achievement. The coding system they developed addressed many of the issues that face teachers, administrators, and researchers who have an interest in the improvement of teaching and learning in their schools. More recently the Tennessee STAR (Student/Teacher Achievement Ratio) project, a large-scale randomized study of student achievement in small classes, used systematically defined categories to answer questions about both short- and long-term academic benefits for students who had been taught in small classes beginning in Kindergarten. The carefully controlled STAR experiment results indicated that there were indeed measurable

[1]Some of these findings resulted from a project supported through a Goals 2000 Hands-On-Science grant as well as by private funding from Tennessee Valley Educators for Excellence.

differences in academic achievement for students in small classes of 13 to17 students compared to those in regular classes of 20 to 25 students (Achilles, 1999; Nye, Achilles, Boyd-Zaharias, Fulton, & Wallenhorst, 1994).

However, the sheer number of extant class size studies has resulted in data of such breadth and complexity that arriving at definitive answers to questions about specific outcomes may seem, at first, to be daunting if not impossible. For example, most small class studies have generally been broadly categorized into outcomes indicators of student achievement, cost-effectiveness, or other benefits for students and schools such as lowering dropout rates and attrition, improving discipline, attendance, and motivating students to succeed in college or work. Much of the class size research has of necessity consisted of small scale studies and therefore has been difficult to generalize to other populations (Nye, Hedges, & Konstantopolous, 1999). For example, one of the most influential advocates of small classes in Tennessee, Helen Bain, conducted a pilot study at a Nashville elementary school that showed promising results, with 14% more students in smaller classes than in larger classes achieving at higher than expected levels (Ritter & Boruch, 1999; Whittington, Bain, & Achilles, 1985). These results proved encouraging enough to provide an impetus for a large scale longitudinal study conducted in 1985-1989 by a consortium of researchers from Vanderbilt University, Tennessee State University, the University of Tennessee at Knoxville, and the University of Memphis. The Nye et al. followup of 79 Project STAR participant schools in 42 districts indicated that students who had more years in small classes in Grades K through 3 had higher achievement in reading and math and that the effects remained measurable through Grade 8. Among the variables included in the five year followup were number of years students were in small classes; school location in inner-city, rural, or urban location;

percentage of Black students; and student gender. For the followup study the achievement indicator was student scores on the Stanford Achievement Test. For the initial studies of elementary school achievement the dependent variables were scores on the California Test of Basic Skills (CTBS) in math, reading, and science.

Finn and Achilles (1999) published results of the STAR project showing that effect sizes for word study skills, reading, and mathematics in Grades 1 and 2 for students in small classes were consistently above .3 for minority students and from .11 to .22 for white students. The additional percent passing Basic Skills First for students in small classes compared to those in regular classes ranged from 5% to nearly 10%. They found that in Grade 4 the students in small classes "exhibited superior engagement behaviors" (p. 99) characterized by fewer discipline problems and higher levels of initiative in active learning behaviors. Expressed in terms of grade equivalents (GEs), Finn and Achilles found that at the end of Grade 5 small class students were approximately one half school year ahead of students who had been in regular classes, even if the students were placed in regular classes beginning in Grade 4.

The STAR findings were additionally cross-validated in a RAND study that used results of NAEP assessments (Grissmer, Flanagan, Kawata, & Williamson, 2000).Grissmer et al. concluded that some of the STAR research may have underestimated the actual small class effect sizes by as much as .2 standard deviation; i.e., for some groups of students the long-term effects of being in a small class for four years were as high as .4 standard deviations. They estimated the small class cost at approximately $150 per pupil per 0.10 standard deviation gain in student achievement based on an average per pupil expenditure in 1993-1994 of $4,400. I provide additional correlations between class size and NAEP data later in this paper.

Although all Tennessee schools were invited to participate in Project STAR if they were willing to comply with the conditions of the experiment, the STAR schools were not a representative sample of Tennessee schools. Participant schools had higher percentages of minority students (33%) and students at the poverty level (50%-60%) than the average for schools and districts across the state of Tennessee (Grissmer et al.).

In addition to measurable benefits in student achievement, Krueger and Whitmore (1998) found that poor and minority students who had been in smaller classes were more likely to take the Scholastic Aptitude Test (SAT) than were similar students who had not been in small classes in elementary school. Taking college entrance exams has been associated with motivation and higher academic aspirations. Krueger (1999) examined the STAR research design, specifically addressing issues of random assignment, attrition, contamination, and variables for teacher and student characteristics. A consistent issue in longitudinal studies is attrition (i.e., original participants who drop out during the course of the study) and contamination (students who switch from one treatment condition to another). For example, only about half of the original group of STAR Kindergarten students remained in the study through Grade 4. Krueger found that in the STAR study, students assigned to small classes were more likely to be assigned to classes with the same classmates each year while students in regular classes generally had new classmates each year, thus possibly creating a cohort or peer group effect for the small class students. Students who were switched from their original random class assignment to one of the other treatment conditions represented only .3 percent of a sample of 1,581 students from 18 STAR schools.

Hanushek's (1999) independent analysis of the econometric efficacy of reduced class size pointed out that the majority of information has been drawn from nonexperimental data collected by schools and school districts, as has the present analysis. While the STAR experimental design showed significant differences in achievement for students in small classes, Hanushek's examination of nonexperimental data failed to support consistent differences in student achievement as a function of class size. Hanushek and others repeatedly point out that PTR and class size are not synonymous; in fact, lower pupil-teacher ratios are often linked to an increase in the number of students assigned to small special education classes rather than to reduced class sizes for all students. Thus, lower PTR may not be reflected by an increase in the number of smaller classes for regular students, and, by extension, to higher levels of achievement for those students. Miller-Whitehead's (2002) analysis of a random sample of Tennessee school districts in the upper and lower quartiles of 1998 Grade 5 science achievement indicated that higher mean science achievement was positively correlated to the percentage of classes at or below state class size guidelines within the school district ($r = .49$, $p < .01$).

Although the Tennessee Project STAR study has received the most national attention, other states and school districts have conducted class size studies and at least eighteen states have class size reduction initiatives in various stages of implementation. In a study of 29,544 students in 690 Alabama schools, Ferguson and Ladd (1996) found significant differences in reading and math achievement for Grade 4 students in small classes. Pointing to the problems often encountered when using PTR as a variable, their study identified small classes as those with fewer than 19 students. A synthesis of class size studies conducted for the U. S. Department of Education (Cohen, Miller, Stonehill, & Geddes, 2000) as part of a comprehensive national class size reduction program concluded that reducing the pupil-teacher ratio, improving Kindergarten programs, and providing more adequate teaching resources should be priorities for states with higher percentages of minority and poor students (p. 12).

For many of the aforementioned reasons, a corollary to class size research has been to examine the relationship between PTR and class size as it relates to student achievement. The decision to use class size or pupil-teacher ratio (PTR) in an analysis may provide very different information about how teaching is organized within a school and yield different results about student achievement. The Project STAR researchers have found widespread misconceptions and confusion among both educators and the general public about the importance of differentiating between PTR and class size, particularly in analyses of student achievement (Achilles, 1999; Achilles, Finn, & Pate-Bain, 2002). Achilles (1998) asserts, "class size influences student outcome positively and PTR doesn't" (p. 6). In the present analysis, the author found that the relationship between class size and student science achievement was about twice that between PTR and student science achievement.

Taking a "macro" approach, using 1998 district-level data for Tennessee, the correlation between PTR and a transformed percentage of classes in school districts within state class size guidelines was .28 ($\underline{p} < .01$). It is easy to see here that PTR and class size are far from synonymous, for if they were the correlation between them would be 1.00! Table 1 provides correlations for class size, PTR, district enrollment, percent of students qualified for free or reduced price meals, median family income, percent minority students, median family income, and per pupil expenditure. Because the differences between PTR and class size can significantly effect results of analyses, researchers should be careful to state whether results are based on PTR or actual numbers of students who were taught in a classroom by a particular teacher. The percentage of classes in a district within or below state class size guidelines accounted for as much as 3% of between-district differences in science achievement, while school district PTR accounted for approximately 1% of differences in student science achievement. However, extensive research on correlates of student achievement indicates that within-district differences are frequently greater than between-district differences. Therefore, it would be expected that between-school differences would result in greater effects for class size than would between-district differences; thus the present analysis may substantially underestimate the actual effect of class size on student achievement in science.

I turn now to the "micro" context of several classes at one or two schools. For example, a configuration for a K-5 elementary school with an enrollment of approximately 700 students might include 29 classroom teachers, 9 teaching assistants, 2 Reading Recovery teachers, 1 Title One teacher, 1 P.E. teacher, and 2 Special Education teachers plus a principal, librarian, guidance counselor and staff. The PTR for this configuration, including the T.A.s, Reading Recovery teachers, and Special Ed teachers, is approximately 16:1. However, PTR generally includes all professional staff at the school, and if the principal, librarian, and guidance counselor are included the ratio becomes closer to 15:1. If only the 29 classroom teachers are counted, the school's PTR is approximately 24:1, which is a closer approximation of what actual class sizes might be in this school. Therefore, within this hypothetical school perhaps one or two classes might be configured as STAR experimental small classes of 13 to 17 students in a class (usually a 15:1 ratio), while others would be regular classes of about 25:1 or regular classes of 25:1 plus a teacher aide, thus providing three experimental student/teacher ratio groupings within the same school. For this example, there could be a difference of as many as 9 or 10 students in a class if PTR were provided rather than the actual number of students. As it happens, although this school predominately used a regular class with aide (RA) model, the pre-first classes were all small (S) classes. I discuss results in the following sections of this paper.

Methodology and Results

The data were 1998 Grade 8 science achievement mean scale scores for 138 Tennessee public school districts. A previous analysis by Miller-Whitehead (2002) had found that the percent of classes in a school district at or below class size guidelines was significantly related to Grade 5 student achievement for a random sample of school districts in the upper and lower quartile of science performance. The present analysis examined data for districts in the upper and lower quintile of Grade 8 science achievement ($n = 52$) in addition to the total population of 138 districts. The dependent variable was district aggregate science achievement on the 1997-1998 TerraNova assessment administered to public school students in Tennessee. Independent variables were percentage of classes within the district that were at or below state-mandated class size, district per pupil expenditure, and percentage of students in the district qualified for free or reduced price meals. The ratio of cases to independent variables was comfortably above the recommended 30:1 for the regression analysis, although researchers have suggested that this ratio depends upon the degree of accuracy and precision required by the study. The regression equation yielded an $\underline{R}$ of .49, an $\underline{R}^2$ of .24, and an adjusted $\underline{R}^2$ of .22. $\underline{R}$ for the regression was significantly different from zero, $F(3, 129) = 13.44$, $p < .01$. The 95% confidence limits for class size were 1.380 to 13.970 and for poverty were -41.716 to -19.061, therefore we could be quite confident that the effects of both class size and poverty were significantly different from zero. Per pupil expenditure was significant in the equation and the eigenvalue for this variable indicated that it was highly dependent with the constant. Correlations are provided in Table 1, a summary of the regression analysis in Table 2, and characteristics of districts at the upper and lower quintile of science achievement in Table 3.

Insert Table 1 about here

A regression analysis for predictors of class size was also conducted, with district enrollment, percentage of students in poverty, and per pupil expenditure as predictor variables. This regression equation yielded an R of .39, an R^2 of .15, and an adjusted R^2 of .13. The results of analysis of variance indicated that the R for the regression was significantly different from zero, $F(3, 132) = 7.86$, $p < .01$. The variables in this regression accounted for approximately 13% of the variability in percentage of classes within a school district meeting class size requirements. Not surprisingly, districts with higher enrollments were less likely to have higher percentages of small classes than were smaller districts, and larger percentages of small classes were significant for districts with higher per pupil expenditures and higher percentages of students in poverty.

The results of the regression analyses indicate that several variables had both a direct and indirect effect on student achievement. Class size had a direct effect on student achievement, as did student poverty and per pupil expenditure; however, student poverty and per pupil expenditure also effected class size.

To present the findings in another way, Grade 8 science achievement was coded into quintiles. Table 3 provides a comparison of the characteristics of school districts in the upper quintile of Grade 8 science achievement with that of districts in the lowest quintile. Districts in the upper quintile had higher percentages of classes at or below state class size requirements than did those in the lowest quintile. Not unexpectedly, the highest achieving districts also had significantly higher per pupil expenditures than did the lowest performing districts.

Insert Table 2 about here

Correlations between class size, PTR, and mean district science achievement were conducted for Grades 3 through 8. Figure 1 shows the relationship between the squared correlation coefficients for class size and PTR with science achievement at each grade level as well as trend lines for each, assuming a linear relationship. The trend lines for class size and PTR provided in Figure 1 provide evidence that lower PTR does not have either as large an effect as class size nor a lasting effect beyond that for the current year for each grade level, while for class size there is an overall upward trend at each grade level for districts with higher percentages of classes at or below state required class sizes.

Insert Figure 1 about here

Insert Table 3 about here

In addition to student achievement, lower class size has been linked to other nonachievement outcomes that may or may not have a direct effect on student achievement.

Generally, such effects are somewhat more difficult to measure and definitive answers await additional research. For example, do teachers of small classes use different teaching strategies than teachers of larger classes? Do students in small classes receive more individual attention? Are students more motivated to achieve in small classes? Is teacher morale higher? In a survey conducted by the U.S. Department of Education, teachers were asked their opinions about the most effective steps that could be taken to keep teachers in the profession. Reducing class size was one of the top five responses, following only higher salary, better strategies for handling discipline problems, and giving teachers more authority. Class size was also a top five response for teachers who indicated that they themselves were dissatisfied with teaching conditions, following student discipline, poor student motivation, and inadequate administrative support. Figure 2 shows the percentages of responses given by a national sample of teachers who were surveyed about their opinions on effective steps to keep teachers.

Insert Figure 2 about here

Turning to the "micro" level, i.e., several classes at one or two schools, there is also evidence in favor of the small class model. For example, one school in a rural part of a county used multiple interventions, including small classes, to provide developmentally appropriate educational opportunities to its K-5 student population. Kindergarten and pre-first classes were small (S) classes, although most classes at several grade levels were configured as RA. The school participated in the Reading Recovery program and employed a Title 1 teacher. Additionally, the school obtained funding for an after-school reading lab for students, also configured as a small class (S). Within the same county school system several other schools were qualified for Title 1 funding. Another group of elementary schools, in a more affluent part of the county, did not have Title 1 programs. The Title 1 schools allocated part of these funds for class size reduction (CSR).

Mean science scores and gain scores for these schools are provided in Table 4. For comparison purposes, schools were identified as either low SES (Title 1) or high SES (not qualified for Title 1). Table 4 indicates that low SES schools had higher value-added gain scores than did high SES schools, and by Grade 5 there was no difference in the average mean science scores for the group of low SES schools compared to the average for the group of high SES schools. These results appear to support the findings of the macroanalysis shown in Figure 1, which indicated that there was a residual achievement gain in later grades for students who were in small classes at least in grades K-3.

Insert Table 4 about here

Although the present study did find that schools were able to re-allocate Title 1 funding to provide small classes, it did not attempt to address such variables as time-on-task, systemic change, individualized instruction techniques, and other teaching innovations that have been made possible through CSR initiatives (Egelson, Achilles, Finn, & Harmon, 1999).

Discussion

Most small class or CSR studies have addressed student achievement in reading, math, and language arts primarily because these are the main areas in which students are assessed in grades K-3. Also, reading and language arts skills provide children in grades K-3 with the foundation for future learning. The present paper takes a somewhat different approach in that it is an extension of an earlier study of the effects of class size and other indicators on student science achievement (Miller-Whitehead, 2002).

Experienced teachers and administrators generally know a great deal about how their students learn, but it is often difficult for them to determine how their students are doing compared to their peers in other schools or school districts. While a micro approach provides an enormous amount of valuable information about how programs are actually implemented under field conditions, active participants may work with such small numbers of students that assessment of differences between treatment and comparison groups, although possible, is difficult. When these data were collected, for example, several schools (Table 4) were participating in a Hands-On-Science consortium as part of a collaboration with Tennessee State University's Center of Excellence for Research in Basic Skills. Although participant schools were not identified in this paper, a goal of the Hands-On-Science project was to assure that students in low income schools and school districts were provided with necessary materials and supplies to achieve at the same level as students in more affluent areas. This goal was to be achieved through smaller classes and through training a cadre of teachers who would be school leaders in science education reform. The data in Table 4 show that during this project many of the lower SES schools were, in fact, able to achieve at or above the levels of the higher SES schools in the same school district. Having an opportunity to meet and work with these teachers and school administrators provided information about teaching and learning in schools that is not possible to consider when using only the broader categories and indicators of a macroanalysis. I have referred to this phenomenon as "the importance of being disaggregated." For example, at the micro level of analysis we know which grade levels and teachers have participated in training and professional development activities, and which schools and teachers will have to wait until the next year!

At the macro level, it is easier to generalize results. The outstanding teachers and school principals who are true instructional leaders within their schools do not have as great an effect on results (the so-called "Hawthorne effect") at the macro level. Thus, the effects of the initiative, in this case CSR, are less affected by issues of implementation and leadership. In other words, at the macro level it is somewhat easier to determine the likely results of an initiative under average circumstances.

In the present study, school districts that had implemented CSR so that all classes in the schools were at or below state recommended class size guidelines had higher Grade 8 science achievement than those districts that did not. Poorer districts were often more likely to have a greater percentage of small classes than were more wealthy districts, at least partly because of entitlement program funding not available for wealthier districts. Although not within the scope of this paper, both smaller classes and higher teacher salaries are components of per pupil expenditure. Followup studies might examine these relationships as correlates of student achievement. The regression model accounted for approximately 22% of the explained variability in Grade 8 mean science achievement. After controlling for the effects of poverty, there was an 8 point increase in mean science achievement for each percentage of increase in classes within a school district that were at or below the state recommended class size. Nye et al. (1999) had found a positive effect for Grade 8 science for students who had been in small classes in K-3, but not as large an effect as that of their Grade 3 science achievement.

Also, results of a national survey indicated that while reducing class size was not teachers' highest concern, it was one of their top five concerns. Several of their other concerns related to student motivation and achievement, issues that may also be alleviated by class size reduction initiatives.

In conclusion, the present study provides evidence of the efficacy of class size as a correlate of student achievement in science at Grade 8. Furthermore, much of the extant class size research has examined student achievement in reading and math. The present study extends these findings to student achievement in science.

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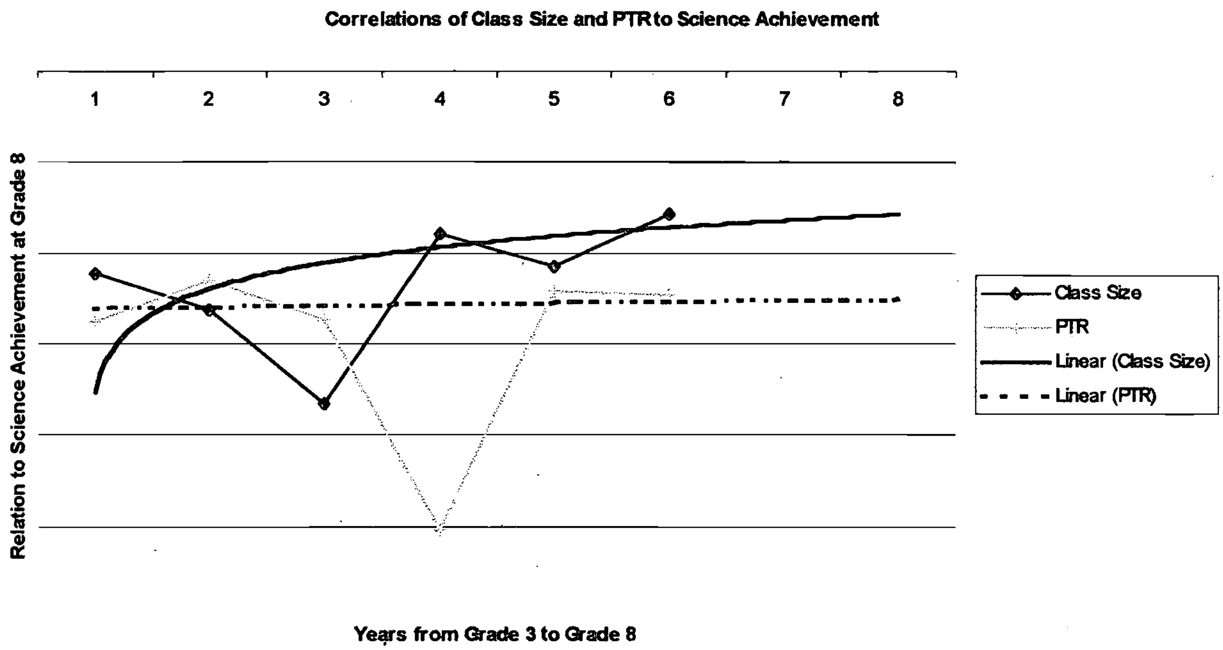

Figure 1. Correlation of the squared correlation coefficient of Class Size and PTR to science achievement for Grades 3 through 8. Projected trend lines for two additional testing years are provided, assuming a linear relationship.

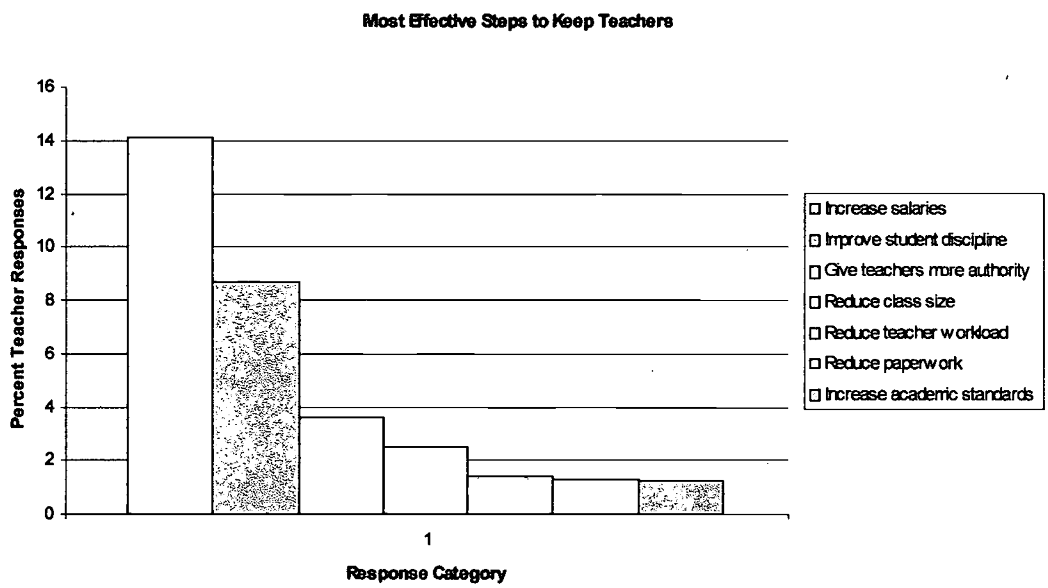

Figure 2. Top teacher opinions about most effective steps to keep teachers in the teaching profession based on results of a national survey conducted by the U. S. Department of Education (1994).

Table 1

Correlations Between PTR, Poverty, Per Pupil Expenditure, Median Income, Enrollment, Minority, and Class Size (N = 138)

	PTR	Poverty	PerPupil$	Income	Enrollment	Minority	Class Size
PTR	--	.025	-.322**	.128	.145*	.045	-.276**
Poverty		--	-.072	-.674**	-.059	.254**	.148*
PerPupil$			–	.171*	.197*	.253**	.181*
Income				–	.406**	.080	-.276**
Enrollment					–	.419**	-.249**
Minority						–	.022
Class Size							--

Note. Income is median family income. Minority was computed as 1 - percent white students.

* $p < .05$, ** $p < .01$, one-tailed.

Table 2

Summary of Regression Analysis for Variables Predicting School District Grade 8 Science Achievement (N = 138)

Variable	B	SE B	β
(Intercept)	679.79	6.37	
Percent within class size	7.68	3.18	.19*
Percent poverty	-30.39	5.73	-.42**
Per pupil expenditure	.003	.00	.18*

Note. R^2 = .24, Adj. R^2 = .22 with science achievement dependent.

Table 3

Characteristics of School Districts in Upper and Lower Quintiles of Grade 8 Science Achievement (N = 52)

Variable	Lower Quintile		Upper Quintile		ES
	M	SD	M	SD	
Percent at class size	62	.29	73	.27	.4
County per capita income	15879	3476.00	16942	4062.00	.3
Percent at poverty	52	.19	43	.14	-1.1
Per pupil expenditure	4161	473.00	4731	797.00	.9

Note. Per pupil expenditures are 1997-1998 dollars; county per capita income from 1990 Census data. All other data from the 1997-1998 Tennessee Education Report Card.

Table 4

Comparison of Science Achievement at Grades 4 and 5 for Low and High SES Schools (N = 15)

Variable	School SES	
	Low	High
	n = 7	n = 8
G 4 mean science score	644	666
G 4 average percent gain	128	95
G 5 mean science score	669	669
G 5 average percent gain	96	45

Note. The average gain shown for Grade 4 was for a 3 year period representing student achievement scores at Grades 2, 3, and 4. The average gain shown for Grade 5 was for a 3 year period representing student achievement scores at Grades 3, 4, and 5. Low SES schools had more small classes than did High SES schools, and had small classes for Kindergarten and pre-first students.

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