Washington State Institute for Public Policy

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K–12 Class Size Reductions and Student Outcomes: *A Review of the Evidence and Benefit–Cost Analysis*

The Washington State Legislature directed the Washington State Institute for Public Policy (Institute) to develop *"a repository of research and evaluations of the cost-benefits of various K–12 educational programs and services."*[1]

In this report, we analyze a significant policy question for the legislature: do the benefits of reducing the number of students in K–12 classrooms outweigh the costs?

We conducted this analysis by reviewing all of the most credible studies from the United States and elsewhere. We systematically analyzed the studies to estimate whether class size reductions have a cause-and-effect relationship with student outcomes. The national and international research can provide insight for Washington policymakers on whether lowering class size is an evidence-based way to improve student outcomes.

We then calculated whether the long-term monetary benefits of class size reductions outweigh the costs.

The class size policy question is especially relevant for Washington in light of a recent court decision. In 2012, the State Supreme Court ruled unanimously in *McCleary v. State of Washington* that the "State has not complied with its [constitutional] duty to make ample provision for the education of all children in Washington."[2] Identification of evidence-based policies will be important as Washington takes steps to address the Court ruling.

In this report, we first summarize long-term trends in pupil-teacher ratios. We then highlight our findings on the relationship between K–12 class size reductions and student outcomes and present benefit-cost calculations. Third, an appendix provides technical details.

[1] Chapter 372, Laws of 2006.

[2] http://www.courts.wa.gov/opinions/pdf/843627.opn.pdf

Summary

The Washington State Institute for Public Policy analyzed whether reducing class size in the K–12 school system leads to better student outcomes and whether benefits exceed costs.

To investigate, we conducted a systematic review of research by collecting all studies we could find on the topic. We screened for scientific rigor and, for our analysis, only included those studies with the strongest research methods. Most studies were from the United States, while some were from other industrialized countries. We identified 53 credible evaluations of whether class size reductions have a cause-and-effect relationship with student outcomes.

Most of the 53 studies in our review measured student outcomes with standardized test scores; a few examined high school graduation rates. Policymakers, understandably, want schools to produce other outcomes as well, but test scores and school completion are most often measured in the existing research literature.

Our bottom-line finding. In the earliest K–12 grades, reducing class size has a high probability of producing a favorable outcome—that is, where the long-term benefits of reducing class size consistently exceed the costs. In the upper grades, on the other hand, reducing class size poses a substantial risk of an unfavorable outcome—that is, where costs may often exceed benefits.

Next steps. In an upcoming Institute report, due October 2013, the magnitude of this effect will be compared with other educational policy options under consideration in Washington State. We will apply the Institute's economic model to estimate the relative benefits and costs of a variety of evidence-based policy options that improve educational outcomes.

Suggested citation: Aos, S. & Pennucci, A. (2013). *K–12 Class Size Reductions and Student Outcomes: A Review of the Evidence and Benefit-Cost Analysis* (Document No. 13-01-2201). Olympia: Washington State Institute for Public Policy.

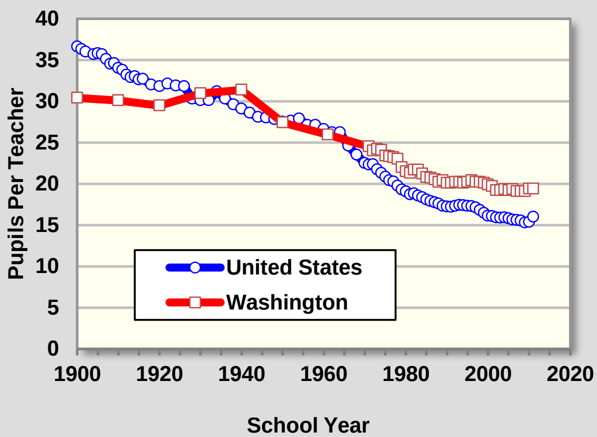
I. Trends in K–12 Pupil-Teacher Ratios

As background, we provide a long-term snapshot on trends in K–12 pupil-teacher ratios in Washington and the United States. The data were obtained from the federal National Center for Education Statistics and the U.S. Census Bureau.[3]

Unfortunately, consistent long-term data do not exist on the actual number of students in an average K–12 classroom in Washington or elsewhere in the United States. The available information describes a different, but related, statistic: the pupil-teacher ratio. A pupil-teacher ratio is calculated simply by dividing the number of enrolled students by the number of teachers. While this is not the same as the actual number of students in a typical classroom, the ratio does provide a useful long-term perspective on the level of instructional personnel available to promote student learning.

Exhibit 1 displays trends from 1900 through the 2010-11 school year. In Washington and in the United States as a whole, pupil-teacher ratios have declined over the long term. This trend implies smaller actual class sizes.

Exhibit 1
K–12 Pupil-Teacher Ratios
in the United States and Washington
1900 to 2011



Note: We were not able to locate consistent historical data for all years. The data points with a circle or square show consistently-defined actual data, while the solid lines are linear interpolations between the actual data points.

In Washington, from 1900 through 1940, there were about 30 students per teacher statewide. In the post-World War II era, the pupil-teacher ratio began to fall. By school year 2010-11, the most recent year for which data are available, the ratio was about 19 students per teacher.

Most of the post-World War II decline in Washington's ratio occurred before 1985. Since 1985, the decline in the number of students per teacher has moderated.

II. Class Size & Student Outcomes

The primary purpose of this report is to estimate the degree to which student outcomes are affected by the number of students in a K–12 classroom.[4] That is, does class size matter, and do the benefits of reducing class sizes outweigh the costs?

This research question has been an active and controversial topic for over four decades.[5] In recent years, a number of studies have used improved data and advanced statistical methods. These rigorous studies provide clearer cause-and-effect estimates of the degree to which reductions in class size affect student outcomes.

Therefore, to investigate the question of whether class size matters, we conducted a systematic review of this research by collecting all studies we could find. Most studies were from the United States while some were from other industrialized countries. In our synthesis of the literature, we included studies with the strongest research designs, and excluded studies with weaker methods.[6]

We found 53 credible evaluations with 77 separate grade-level estimates of the degree to which changes in K–12 class size have a cause-and-effect

[3] U.S. Department of Education, National Center for Education Statistics. *Digest of Education Statistics* (annual publications). The latest NCES data are for school year 2010-11. Data for some early years for Washington were collected from various issues of the Statistical Abstract of the United States published by the United States Census Bureau.

[4] This report updates and extends a 2007 Institute analysis: Aos, S., Miller, M., & Mayfield, J. (2007). *Benefits and Costs of K–12 Educational Policies: Evidence-Based Effects of Class Size Reductions and Full-Day Kindergarten.* Olympia: Washington State Institute for Public Policy, Document No. 07-03-2201.

[5] For the classic reviews highlighting the opposing arguments in this debate, see: R. Greenwald, L.V. Hedges, & R.D. Laine. (1996). The effect of school resources on student achievement. *Review of Educational Research*, *66*(3): 361-396. E.A. Hanushek. (1996). A more complete picture of school resource policies. *Review of Educational Research*, *66*(3): 361-396.

[6] The Institute's approach to conducting meta-analyses is described fully in: Lee, S., Aos, S., Drake, E., Pennucci, A., Miller, M., & Anderson, L. (2012). *Return on investment: Evidence-based options to improve statewide outcomes, Technical Appendix Methods and User-Manual, April 2012* (Document No. 12-04-1201B). Olympia: Washington State Institute for Public Policy.

relationship with student outcomes. The student outcomes measured in these studies include standardized test scores, high school graduation rates, and dropout rates. Policymakers, understandably, want schools to produce other outcomes as well, but test scores and school completion are the outcomes most often measured in the existing research literature.

It is important to note that our review is not an evaluation of whether reductions in class size in Washington have affected student outcomes. Rather, this analysis uses the best national and international research to provide policymakers with insights into the likely relationship in Washington.

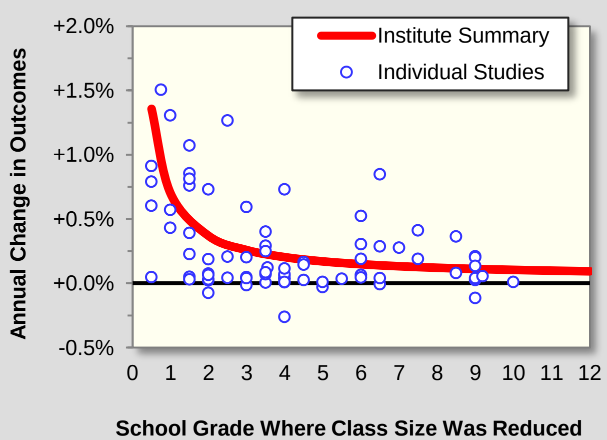
Two results emerged from our review of the research on class size. First, the weight of the evidence indicates that, on average, class size is related to student outcomes—smaller class sizes improve outcomes, although the overall effect appears to be small. Second, the positive effect of lowering class size is much stronger in lower school grades and weaker in the upper grades.

Exhibit 2 displays these results. In the exhibit, the effect from each of the 53 studies (and their 77 grade-level effects) is plotted as a circle. Our statistical summary is the solid line. The relationship displayed is what economists call an "elasticity"—how, for example, a 10% reduction in class size leads to a one-year percentage change in student outcomes.

Exhibit 2

Results from our Review of Class Size Research:

How a 10% Reduction in Class Size Leads to an Annual Change in Student Outcomes



The exhibit reveals considerable variation in the individual estimates; some show that reduced class sizes have larger effects on outcomes while others show virtually no effect. Our summary (the solid line) is a weighted average of all of the studies—this is our "best estimate" of the true relationship, given the results of all of the most credible research to date.[7]

Benefit-cost analysis. The results shown in Exhibit 2 only indicate that, on average, student outcomes improve when class size is reduced—particularly in lower grades.

This finding by itself, however, does not reveal whether reducing class size is an economically attractive policy. Since tax dollars pay for reductions in class size, the relevant economic question is whether benefits outweigh costs.

Therefore, we used the findings from Exhibit 2 along with Institute's benefit-cost model to compute bottom-line estimates.[8]

Costs. We first calculated the per-student cost to Washington taxpayers to reduce class size by one student per class, from current levels. Our cost estimates, by grade level, are shown in column two of Exhibit 3 (next page). We find, for example, that reducing class size by one student from current levels in first grade costs Washington taxpayers about $198 per student, per year. In October 2011, roughly 79,000 first grade students were enrolled in Washington public schools, so the total annual taxpayer cost to reduce class size by one student per class in first grade would be roughly $15.6 million. These costs account for state and school district teacher salary and benefits expenses, along with some other marginal operating costs. We also include increased capital cost amortization in this estimate. The details of these cost calculations are described in the Technical Appendix.

Benefits. We then calculated monetary benefits from the improved student outcomes shown in Exhibit 2. We monetized the student gains by employing a set of procedures often used by economists. If students do better on standardized test scores, researchers have found that their lifetime labor market earnings increase.[9] Similarly, if students graduate from high

[7] We follow standard meta-analytic procedures and use random effects inverse variance weights to calculate the averages.

[8] See Lee et al., 2012, for detail about the Institute's benefit-cost model.

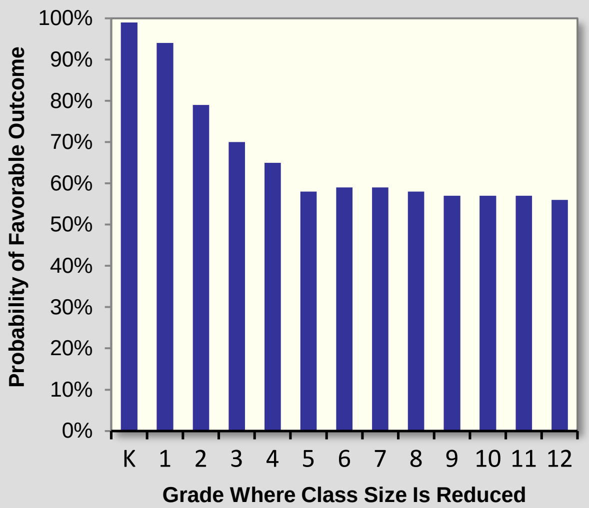
[9] Hall. (2011). "Adolescent cognitive skills, attitudinal/behavioral traits and career wages." *Social Forces, 89*(4), 1261-1285; also see: Hanushek, E. A. (2009). The economic value of education

Exhibit 3
Per-Student Benefits and Costs of Reducing Class Size by One Student Per Class in Grades K–12 in Washington

Grade	Costs, Per Student	Average Benefits, Per Student	Average Net Value, Per Student	Risk : Probability Class Size Reduction at Least Breaks Even
1	2	3	4	5
K	$198	$2,302	$2,104	99%
1	$198	$1,218	$1,021	94%
2	$198	$725	$528	79%
3	$198	$578	$381	70%
4	$179	$422	$243	65%
5	$179	$366	$187	58%
6	$179	$347	$168	59%
7	$162	$358	$196	59%
8	$162	$336	$175	58%
9	$160	$306	$146	57%
10	$160	$301	$141	57%
11	$160	$378	$218	57%
12	$160	$353	$193	56%

All dollars are denominated in 2011 dollars. The costs include both state and district costs of lowering class size by one student per class. The benefits are in life-cycle present value dollars. See the Technical Appendix for details.

Exhibit 4
The Probability that Lowering Class Size Produces a Favorable Outcome, Where Benefits Exceed Costs



and cognitive skills. In G. Sykes, B. Schneider, & D. Plank (Eds.), *Handbook of education policy research* (pp. 39-56). New York: Routledge.

school, they can be expected to earn more money over their lifetimes than those who do not graduate.[10] Other benefits of enhanced educational performance include improvements in the overall rate of economic growth,[11] reductions in the probability of future criminality,[12] and lower public health care costs.[13] The Institute's benefit-cost model provides a consistent approach to quantifying these benefits.[14]

In the third column in Exhibit 3, we display our estimates of the average benefits per student of lowering class size by one student per class in each grade level.

For example, we find that a one-student class size reduction from current levels in first grade produces $1,218 in benefits per student. These benefits, which flow from the improved academic performance, are the present-valued life-cycle gains in improved labor market performance and overall economic growth, reduced criminality, and lowered health care costs.

The fourth column in Exhibit 3 displays the average net present value (benefits minus costs), per student, by grade level. On average, the net benefits of class size reductions are substantially larger in earlier grades than in later grades.

Risk. All predictions involve risk, including our estimates of the benefits and costs of reducing class size. Some of the risk reflects the variation in the effects shown in Exhibit 2, while other risks stem from how we monetize the benefits of improved student outcomes. We assessed the risk in our conclusions by varying each of these factors and running our economic analysis thousands of times.[15]

Our risk analysis allowed us to calculate a single summary statistic that we think provides a fair answer to the question of whether class size reductions offers Washington policymakers an evidence-based and economically sound way to

[10] Heckman, J., Lochner, P., & Todd, P. (2008). Earnings functions and rates of return. *Journal of Human Capital, 2*(1), 1-31.

[11] McMahon, M. (2010). The external benefits of education. In D.J. Brewer & P.J. McEwan, eds. *Economics of education*. Oxford, UK: Academic Press.

[12] Lochner, L., Moretti, E. (2004). The effect of education on crime: Evidence from prison inmates, arrests, and self-reports. *American Economic Review, 94*(1), 155-189.

[13] Belfield, C., Hollands, F., & Levin, H. (2011). What are the Social and Economic Returns? New York: Columbia University, Teachers College, The Campaign for Educational Equity.

[14] For details on the Institute's benefit-cost methods, see Lee, et al., (2012), Technical Appendix.

[15] For technical readers, we conducted a Monte Carlo simulation.

improve student outcomes. That statistic is the probability that reducing class size produces a favorable outcome, where benefits are greater than or equal to costs.

The results of the risk calculations are shown in the fifth column in Exhibit 3 and plotted in Exhibit 4 (previous page). They indicate that the odds of a favorable outcome from lowering class size in the early grades are very high. For example, our calculations indicate that lowering class size by one student in first grade from current levels has a 94% chance of producing long-term benefits that exceed costs. Put another way, we find a low probability—just 6%—of an unfavorable outcome from class size reductions in first grade. An investment with only a 6% chance of a negative outcome can be regarded as a safe investment.

This favorable outcome in the early grades, however, diminishes significantly at higher grade levels. By grade 9, for example, the chance of a favorable outcome (where benefits exceed costs) reduces to just 57%. This implies that the chance of an unfavorable outcome, where costs exceed benefits, is 43%. An investment with a 43% chance of a negative outcome can be regarded as a risky investment.

Key Finding. The bottom-line finding from our analysis of the evidence and economics of class size reduction is that in the earliest K–12 grades reducing class size has a high probability of producing a favorable outcome—that is, where the long-term benefits of reducing class size consistently exceed the costs. In the upper grades, on the other hand, reducing class size poses a substantial risk of an unfavorable outcome—that is, where costs may often exceed benefits.

Next Steps. The research presented in this report is part of a larger Institute study examining a wide array of policies to increase Washington's high school graduation rate.[16] The Institute's final report on this topic will be completed by October 2013. The project will apply the Institute's standard benefit-cost model to estimate the relative economics of different combinations of policy options, including those aimed at improving teaching effectiveness. The Institute has previously found that policies focused on enhancing teaching effectiveness can have large impacts on student achievement.[17]

As the Legislature continues to reform K–12 education and address the Supreme Court *McCleary* ruling, this information may be helpful in crafting a set of evidence-based policies that use taxpayer dollars efficiently to improve student outcomes in Washington.

[16] This project is funded by the MacArthur Foundation and was approved by the Institute's Board of Directors.

[17] Aos, S., Miller, M., & Pennucci, A. (2007). *Report to the Joint Task Force on Basic Education Finance: School employee compensation and student outcomes.* Olympia: Washington State Institute for Public Policy, Document No. 07-12-2201.

Meta-Analysis

If K–12 class size is reduced, is there reason to believe that student outcomes will also increase and, if so, by how much? To analyze this policy question, the Washington State Institute for Public Policy conducted a systematic review of research evidence. We gathered all the studies we could locate on the topic; most were from the United States while some were from other industrialized countries. We screened the studies for scientific rigor and, for our analysis, only included those with the strongest research designs. Based on this body of research, we then estimated the expected effect of K–12 class size reductions on measured student outcomes.

Most research literature on the effect of class size on student outcomes uses an econometric estimation of a production function. Typically, these regressions use a continuous variable representing class size to predict either continuously measured test scores or dichotomously measured graduation rates. The coefficients from these studies can usually be expressed as elasticities. An elasticity measures how a percentage change in one variable leads to a percentage change in another variable. For this study, we calculated an elasticity measuring the degree to which a 10% reduction in class size leads to a percentage change in student outcomes.

For each study included in our review of the literature, we computed an elasticity from each author's preferred regression coefficients. We also collected information from each study that allowed us to: (a) calculate an inverse variance weight, and (b) impute an intra-class correlation to account for clustering levels contained in this wide array of studies.

Since the development of human capital can be viewed as a multi-year process,[18] and since the studies in our review estimated elasticities that cover different grade intervals between measured outcomes and prior outcomes, we developed a procedure to standardize each study's elasticity. For each study, we calculated an *annualized* elasticity that, when applied to the number of "investment years" measured in the study, would reproduce the study's total elasticity. The annualized elasticity is calculated as:

$AnnElas_s = (1+Elas_s)^{\wedge(1/Nper_s)} - 1$,

where for each study, *s*, an annualized elasticity for a 10% reduction in class size, $AnnElas_s$, is computed as one plus the elasticity measured in the study, $Elas_s$, raised to one divided by the number of years K–12 class size is reduced in the study, $Nper_s$, minus one.

$Nper_s = OutcomeGrade_s - PriorOutcomeGrade_s$,

where the number of annual investments included in a study, $Nper_s$, is the difference between the grade at which the outcome is measured in the regression's dependent variable, $OutcomeGrade_s$, and the grade of a prior outcome included as a covariate in a study's regression, $PriorOutcomeGrade_s$. If no prior outcome is included in a study's production function (i.e., if it is not a "value added" production function), then $PriorOutcomeGrade_s$ is set to zero.

We then meta-analyzed the annualized elasticities for this group of studies using an inverse-variance random effects model.[19] The meta-analysis included 77 effects from 53 separate studies. Some studies measured outcomes at two different grade levels and each grade level estimate was included in the meta analysis. If a study measured both reading and math test scores at the same grade level, we averaged the two effect sizes to minimize problems of independence of observations. The citations to the studies included in our review are listed at the end of this appendix.

The regression results are shown in Exhibit T1. First, we ran a constant-only model to compute a random effects meta-analytic result. The statistically significant effect is an annualized elasticity of .0279 with a standard error of .0050. Thus, for a 10 percent reduction in class size, the estimated effect would be an average gain in student outcomes of .279 percent.

Next, to analyze this basic meta-analytic finding in greater detail, we conducted a regression analysis of the 77 annualized elasticities. We were particularly interested in testing whether results were stronger in lower grades than in upper grades. In the regressions, we controlled for: (a) the average grade level measured in each study—a study's annualized elasticity was coded at the mid-point of its *Nper* range; (b) whether the study used a research method that included either random assignment, instrumental variables, regression discontinuity, or value added estimation strategy (coded 1)—the remaining studies typically used fixed effects multivariate specifications (coded 0); (c) the type of outcome measured—a dummy-coded variable was created for high school graduation (coded 1) or standardized test scores on math or reading (coded 0); (d) whether the study recorded a pupil-teacher ratio as the independent variable of interest (coded 1) or actual class size (coded 2), and (e) whether the study was from outside the United States (coded 1) or the United States (coded 0). The inverse variance weights from the random effects meta-analysis were used in weighted ordinary least squares regression (WLS).

Exhibit T1 shows these meta-regression results (model 2). We experimented with a number of functional forms for the GRADELEVEL variable, including linear, quadratic, cubic, and log models. The best fitting model was a simple reciprocal functional form. None of the other study characteristics were significant, but we include them in the final model.

[18] Todd, P. E., & Wolpin, K. I. (2003). On the Specification and Estimation of the Production Function for Cognitive Achievement. *The Economic Journal, 113*(485), 3-33.
[19] The Institute's approach to conducting meta-analyses is described fully in Lee et al., 2012.

Exhibit T1
Least Squares Meta Regression Results

	Coef	SE	t	p-value
Model 1				
Constant Only	0.0279	0.0050	5.5928	0.0000
Model 2				
Constant	-0.0010	0.0131	-0.079	0.938
1/GRADELEVEL	0.0659	0.0199	3.310	0.002
METHOD	0.0043	0.0107	0.398	0.692
HSGRAD OUTCOME	0.0098	0.0093	1.057	0.294
PUPIL-TEACHERRATIO	0.0010	0.0125	0.084	0.933
NON-US STUDY	-0.0054	0.0089	-0.598	0.552
Model 2 Summary Statistics				
R-squared	0.4394			
Adjusted R-squared	0.3999			
S.E. of regression	0.0334			
Sum squared resid	0.0790			
F-statistic	11.12984			
Mean dependent var	0.0282			
S.D. dependent var	0.0429			
Number of observations	77			
Both models are estimated with White heteroskedasticity-consistent standard errors. The models are estimated with weighted least squares with inverse variance random effects weights.				

Computation Effect Sizes for Use in the Institute Benefit-Cost Model

As described, the meta analysis was conducted by computing an elasticity metric for each study. In order to use the Institute's benefit-cost model to analyze the effects, the elasticity estimates had to be converted into effect sizes based on Cohen's d (for continuous test score outcomes), or the Dcox (for dichotomous high school graduation outcomes). The economic calculations carried out in the Institute's model begin with these effect sizes This section describes the computational routines to convert the elasticity-based effect sizes into Cohen's d or Dcox based effects sizes.

Test Score Outcomes

For continuous test score outcomes, Cohen's d effect sizes are computed as follows:

$$ES1_g = \frac{\left(ELAS_g \times \frac{CS\Delta_g}{CSB_g} \times TS_g\right)}{TSSD_g}$$

and the corresponding standard error for the effect size is computed with:

$$ES1SE_g = ES1_g \times \left(\frac{\sqrt{SER_g^2 + SEAux_g^2}}{ELAS_g}\right)$$

Where,

ES1g is the estimate of Cohen's d effect size at time period one (the grade when the test score was estimated);

ELASg is the mean elasticity estimate at grade g that is derived directly from the regression listed in Exhibit T1;

CSΔg is the change in class size being modeled at grade g (for example, a one student change);

CSBg is the current class size at grade g. For current class size, we used the Washington's average class sizes in the prototypical schools funding model.[20]

TSg is the average scale score for the standardized test being modeled. We used an average of the reading and math scores on the Washington Measurements of Student Progress (MSP) and High School Proficiency Exam (HSPE) from the 2009-10 and 2010-11 school years.

[20] Those class sizes are: grades K-3, 25.23; grades 4-6, 27; grades 7-8, 28.53; and grades 9-12, 28.74. http://www.leg.wa.gov/Senate/Committees/WM/Documents/K-12%20Funding%20Formulas.pdf

TSSDg is the standard deviation for the standardized test being modeled. We used the pooled standard deviations from the 2009-10 and 2010-11 MSP and HSPE.

ES1SEg is the estimated standard error of the effect size at time period one;

SERg is the standard error of the regression (obtained from the regression in Exhibit T1);

SEAuxg is the standard error for the constant term in an auxiliary regression used to isolate the unobserved error the regression shown in Exhibit T1. The auxiliary regression implements the procedure for obtaining standard errors in Wooldridge (2009).[21]

In the Institute's benefit-cost model for effect sizes for test scores, two effect sizes are estimated. The first, shown above, is a measure of the effect size at the age of the student when test scores are measured. It has been observed, however, that gains in test scores "fade out" over time. We model this decay in the Institute's benefit-cost model because it is the test score effects that occur near the end of high school that have the strongest causal link to performance in the labor market. Therefore, we adopt a rate of decay for test score effect sizes. Our decay rate is very similar to those produced by other analysts.[22]

Thus we estimate a second effect size, and standard error, for test scores as follows:

$$ES2_g = ES1_g \times Decay_g$$

The standard error of the second effect is more complicated because it takes into account the combined error in the estimation of the effect size, and the error in the estimation of the decay factor.

$$ES2SE_g = \sqrt{\left(\left(ES2_g \times \left(\frac{\sqrt{SER_g^2 + SEAux_g^2}}{ELAS_g}\right)\right)^2 + SEDecay_g^2\right)}$$

Where,

ES2g is the estimate of Cohen's d effect size at time period two (near the end of high school);

Decayg is the estimated multiplier to convert a test score at grade g to a decayed effect size near the end of high school; and

SEDecayg is the estimated standard error in the decay rate at grade g.

High School Graduation Outcomes

For dichotomous outcomes such as high school graduation, we implement a Dcox effect size computed as follows:

$$ES1_g = \frac{Ln\left(\dfrac{\left(ELAS_g \times \dfrac{CS\Delta_g}{CSB_g} \times GR\right) + GR \times (1 - GR)}{GR \times \left(1 - \left(\left(ELAS_g \times \dfrac{CS\Delta_g}{CSB_g} \times GR_g\right) + GR\right)\right)}\right)}{1.65}$$

and the corresponding standard error for the effect size is computed with:

$$ES1SE_g = ES1_g \times \left(\frac{\sqrt{SER_g^2 + SEAux_g^2}}{ELAS_g}\right)$$

Where the only new variable is GR, the base expected high school graduation rate before the class size reduction. We used the most recently reported statewide on-time high school graduation rate from the 2010-11 school year.[23]

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[21] Wooldridge, Jeffrey M. (2009). *Introductory Econometrics: A Modern Approach, 4e*. Mason, OH: South-Western CENGAGE Learning, pp: 206-210.

[22] The Institute's decay rate is discussed in Lee et al., 2012, page 87. Our results are similar to those found in other analyses of test score fade out. See, e.g., Leak, J., Duncan, G., Li, W., Magnuson, K., Schindler, H., & Yoshikawa, H. (2010, November). *Is timing everything? How early childhood education program impacts vary by starting age, program duration, and time since the end of the program.* Paper prepared for presentation at the meeting of the Association for Policy Analysis and Management, Boston, MA; Camilli, G., Vargas, S., Ryan, S., & Barnett, W. S. (2010). Meta-analysis of the effects of early education interventions on cognitive and social development. *Teachers College Record*, *112*(3), 579-620; Goodman, A. & Sianesi, B. (2005). Early education and children's outcomes: How long do the impacts last? *Fiscal Studies*, *26*(4), 513-548.

[23] In 2010-11, Washington's on-time high school graduation rate was 76.6%. http://www.k12.wa.us/DataAdmin/pubdocs/GradDropout/10-11/GradDropoutStats_2010-11.pdf

Computation of the Per Student Costs of Class Reductions

Exhibit T2
Worksheet to Estimate Per Student Costs of Class-Size Changes
Example Shown: Reducing Class Size by 1 Student in 9th Grade

Item	Example:	**Cost per Student** (teacher cost divided by the class size)	**Change in Cost per Student** from the starting class size to the new class size
Operating Cost Calculations			
Annual teacher cost	$97,244		
class size (starting)	28.74	$3,383.59	
class size (new size)	27.74	$3,505.56	$121.97
Capital Cost Calculations			
Inputs			
Total FTE students in the grouping (i.e. all public K-12 students in Washington, or a subgroup like K-3)			1,032,640
Average square feet of classroom space per student			90
Construction cost for K-12 classrooms (dollars per square foot, 2006 dollars)			$180
Year of dollars for the construction cost estimate			2006
Inflation adjustment using the IPD (PCE) index: 2011/2006			1.106
Length of bonds for new construction			25
Interest rate on bonds			3.46%
Results: Classrooms needed			
At the starting class size (entered above)		35,930	
At the new class size (entered above)		37,226	
Change in the number of classrooms		1,295	
Change in the total square footage for the drop in average class size		3,233,737	
Annual capital amortization costs for the unit drop in average class size		$38,895,613	
Annual capital payment per student			$37.67
Summary			
Total Per-Student Statewide cost (operating and capital) of the class size change			$159.64

Notes:

Annual teacher costs are calculated using the 2011-12 average total (state and local) salary for Washington certificated teachers reported in the Office of Superintendent of Public Instruction School District Personnel Summary Profiles. The calculation includes salaries and benefits as well as central administration and special education costs.

Starting class size is based on the current Washington average class sizes in the state's prototypical schools funding model.

Total student FTEs are reported for the 2011-12 school year.

Assumptions for capital cost calculations were provided by legislative staff, with one exception: the interest rate on bonds is from the Federal Reserve's November 2012 state and local rate.

Institute Analysis of NAEP and CCD Data

One of the studies included in the meta-analysis reported in this paper is the Institute's own analysis of student outcomes and pupil-teacher ratios, not previously published. Using state-level data, we estimated models with the following form:

O = f(PTR, X, S, T, e), where

O represents a student test score or graduation outcome; *PTR* is the per-teacher ratio described below; *X* is a vector of covariates on basic teacher characteristics; *S* is a state fixed effect; *T* is a time fixed effect; and *e* is the error term. We were unable to identify a plausible instrumental variable to use with this dataset.

We collected a balanced panel of state-level data from the National Assessment of Educational Progress (NAEP) for 4^{th} and 8^{th} grade reading and math scale scores, and from the Common Core of Data (CCD), state-level on-time high school graduation rates, teacher education and experience characteristics, and pupil-teacher ratios. The NAEP scores are for 2003, 2007, and 2009. The high school graduation rates include 2002 through 2009.

Annual pupil-teacher ratios and teacher characteristics were averaged for each regression. For 4^{th} grade outcomes, we used the average pupil-teacher ratios and teacher characteristics for the prior four years; for 8^{th} grade outcomes, the prior eight years; and for high school graduation rates, the prior 12 years. We took the natural logarithms of the dependent variables and the pupil-teacher ratio variable so that the coefficient can be read directly as an elasticity.

We conducted an ordinary least squares regression analysis with and without state and time fixed effects. All regressions were estimated with White heteroskedasticity-consistent robust standard errors.

Exhibit T3

	Dependent Variable in Each Regression									
	4^{th} Grade Test Scores				8^{th} Grade Test Scores				High School Graduation	
Independent Variables	ln(reading)		ln(math)		ln(reading)		ln(math)		ln(graduation rate)	
C	5.3036	5.7801	5.3928	5.6681	5.5541	5.7679	5.6856	5.9562	4.8273	6.3575
	(0.1995)	(0.1566)	(0.1918)	(0.1161)	(0.1872)	(0.1343)	(0.2423)	(0.0975)	(0.3886)	(1.0272)
ln (pupil-teacher ratio)	**-0.0687**	**-0.0967**	**-0.0504**	**-0.0566**	-0.0467	-0.0396	**-0.0600**	**-0.0733**	**-0.1230**	**-0.8150**
	(0.0202)	(0.0337)	(0.0192)	(0.021)	(0.0171)	(0.0292)	(0.0207)	(0.0256)	(0.0367)	(0.2197)
% teachers with a master's degree or higher	0.0003	-0.0004	-0.0001	0.0001	0.0000	0.0001	-0.0003	-0.0003	**-0.0025**	0.0008
	(0.0002)	(0.0004)	(0.0002)	(0.0003)	(0.0002)	(0.0002)	(0.0002)	(0.0003)	(0.0004)	(0.0014)
% teachers with 3-9 years of experience	0.0035	-0.0014	0.0032	-0.0005	0.0013	-0.0016	0.0021	-0.0012	-0.0023	0.0028
	(0.0024)	(0.0013)	(0.0023)	(0.0011)	(0.0023)	(0.0011)	(0.003)	(0.001)	(0.0054)	(0.0078)
% teachers with 10-20 years of experience	0.0025	-0.0008	0.0021	-0.0003	0.0019	-0.0003	0.0010	-0.0010	-0.0037	0.0028
	(0.002)	(0.0011)	(0.0019)	(0.0009)	(0.0019)	(0.001)	(0.0025)	(0.0009)	(0.004)	(0.0048)
% teachers with >20 years of experience	**0.0029**	-0.0015	0.0021	-0.0010	0.0017	-0.0013	0.0012	**-0.0015**	0.0045	0.0002
	(0.0017)	(0.0015)	(0.0017)	(0.0011)	(0.0017)	(0.0009)	(0.0021)	(0.0008)	(0.0035)	(0.0065)
State fixed effects?	no	yes	no	yes	no	yes	no	yes	no	yes
Year fixed effects?	no	yes	no	yes	no	yes	no	yes	no	yes
Periods	3	3	3	3	3	3	3	3	8	8
Cross-sections	51	51	51	51	51	51	51	51	51	51
Total obs.	153	153	153	153	153	153	153	153	408	408
R-squared	0.1785	0.9597	0.1048	0.9647	0.1281	0.9704	0.0830	0.9801	0.1910	0.9108

Bolded coefficients are significant at $p < 0.10$. White heteroskedasticity-consistent robust standard errors are in parentheses.

Four of the five class size elasticities in our preferred fixed-effects models were statistically significant at $p < 0.05$; the fifth elasticity, eighth grade reading, had a p-value of 0.18.

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Washington State Institute for Public Policy (2013). The Institute's state-level fixed effects analysis of NAEP and CCD data is reported in this Technical Appendix.

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