Daylighting and Human Performance: Latest Findings

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ABSTRACT

A previous study of the association between more daylighting and better student performance has had dramatic effects on school construction across the country. Programs to encourage the use of daylight in schools have been initiated in states and nationally. The validity of these studies has remained under question until further investigations checking for other potential influences could be completed and other studies replicated the findings.

This paper reports on the status of those efforts. Questions raised during the peer review process of the schools study have since been addressed via re-analysis of the original data, with the addition of self-reported information about the teachers. This paper will report on findings about the influence of a "teacher assignment bias" on the original findings of a daylight effect. In addition, analysis of absenteeism data relative to a "daylighting effect" and sensitivity of students to daylighting by grade level are also reported.

Further studies have collected data on another school district and another chain retailer using daylight. These replication studies have collected more detail about the individual building characteristics that will allow analysis to include greater detail on associated variables such as view, ventilation, and electric lighting effects.

Background on Previous Study

The School Data

The previous report on Daylighting and Productivity in Schools examined the effect of daylighting on one aspect of human performance [HMG1 1999]. The study looked at how daylighting, from windows or skylights, affects the test scores of students in three elementary school districts. We found a statistically compelling connection between daylighting and improved student performance.

Schools were chosen as the subject of the study because we could obtain extensive data on occupant performance for nearly identical buildings. We believe that the conclusions may be transferable to other types of buildings, such as offices and factories, since it is really human performance that we are investigating. If daylighting enhances the performance of children in schools, it is not too large a stretch to suppose that it might also enhance the performance of adults in office buildings or other workplace settings. A similar study linking presence of daylight to higher sales in retail stores has motivated chain retailers across the country to incorporate daylighting into their new store designs [HMG2 1999].

We obtained student performance data from three elementary school districts and looked for a correlation between test scores and the amount of daylight provided by each student's classroom environment. Daylight in the classrooms was assessed on a scale of 0-5 from 0=non-existant to 5=highest quality, i.e. sufficient for teaching purposes most of the school year. We used data from second through fifth grade students in elementary schools because there is extensive data available from highly standardized tests administered to these students, and because elementary school students are generally assigned to one teacher in one classroom for the school year. Thus, we reasoned, if the physical environment does indeed have an effect on student performance, it would be most apparent in populations of elementary school students.

We analyzed test score results for over 7,000 to 9,000 students from each of the three school districts, located in San Juan Capistrano, California; Seattle, Washington; and Fort Collins, Colorado. The districts provided us with a wide variety of test data sets and student demographic characteristics. We used two test scores, reading and math, as the dependent variables for our models. We included from 20 to 50 control variables in the models, depending on the level of information available from the districts and our own on-site data collection. Control variables included student socio-economic status, ethnicity, grade level and school and classroom size for the simpler models, and teacher, classroom, school site, and curriculum characteristics for the more complex models.

Findings of Previous Report

The results of the analyses of the three districts were remarkably consistent: all show positive association of more daylight with better student performance, with highly significant results. The actual magnitude of the effects is less important than the observation that a consistent association has been found in three very different school districts.

From this study, we made a number of important findings:

- We found a uniformly positive and statistically significant correlation between the presence of daylighting and better student test scores in all three districts.
- We found that skylights had the same magnitude and certainty of effect as daylight from windows, strongly suggesting that we were observing a daylight effect, and not some other quality of windows, such as view.
- We found that this methodology of using large, pre-existing data sets can be a successful and powerful tool for investigating the effects of the physical environment on human performance.

We refer the reader to the more detailed report 'Daylighting in Schools' for full discussion.

Objectives of this Study

The earlier study of Daylighting in Schools was reviewed by a panel of experts, from a wide range of disciplines related to the study. In general, the review panel was satisfied with the soundness of the basic methodology and the rigor of the statistical analysis. An additional "classroom level analysis" verified the robustness of the initial results[1]. The peer

[1] This classroom level analysis, reported in the appendix of the first report, indicated that the statistical significance of some of our earlier results may have been slightly overstated, but that the effects of interest were not substantially altered. We decided to continue with the student level of analysis in this study since it provided us with more precision in accounting for student, teacher, classroom and school level influences. A classroom level analysis requires aggregating student demographic information at the classroom level and averaging those effects for all students in a given classroom, whereas a student level analysis can control for individual differences by student.

reviewers, however, expressed two primary concerns that could only be addressed in follow-up studies. These are:

- The results might be confounded by a potential bias whereby "better" teachers might be more likely to be assigned to more daylit classrooms
- The analysis might be more accurate if performed by grade level, rather than aggregating data from four grade levels together

The follow-up study described in this report was designed to address these two concerns, and expand our understanding of methodological choices for further work [HMG 2002]. The study re-analyzed data from the 1997-98 school year student performance data on standardized math and reading tests from the Capistrano Unified School District in Southern California and the Seattle Public School District in Seattle Washington.

Four tasks were defined for this study, which are briefly summarized in this paper: 1) Teacher Survey, 2) Teacher Bias Analysis, 3) Grade Level Analysis, and 4) Absenteeism Analysis.

Teacher Survey

The Teacher Survey surveyed a sub-sample of teachers in the original Capistrano data set to determine their years of teaching experience, education level, and other characteristics that might be associated with being a "better" teacher. While we were conducting this survey, we decided to include a few additional questions to learn more about the teachers' perspective on classroom assignments, their preferences for the physical qualities of classrooms, and how they operated their classrooms.

Methodology

The Capistrano district was not able to provide us information about the characteristics of their teachers. They were, however, willing to allow us to survey a sub-sample of the teachers in the study in order to collect information directly which teachers were will to volunteer.

We identified 14 schools with a balanced sample of all window and skylight conditions found in the original 27 elementary schools included in the 1997-98 database. We sent surveys to every teacher in our original study at these 14 schools. Our goal was to achieve a sufficient sample of teachers in each daylighting condition, in order to have the best chance to achieve statistical confidence in our new analysis. Over the two year period, between the survey and the original data mapping, about 17% of the teachers had left the district or moved to non-teaching jobs and about 6% had re-located to a different school in the district. As a result, our sub-sample of teachers now resided at every elementary school in the district. With a 68% return rate, we netted surveys which represented 42% of the original study population.

A two-page survey instrument, with both structured and open-ended questions, was created; this asked for the teacher’s education level, certificates, additional coursework, special honors, and years of teaching experience. It also asked about the teachers’ experience with room assignments, their preference for physical characteristics and amenities in their classrooms, preferences for portable versus traditional classrooms, their energy management activities and general comments.

The teacher characteristic information—years of experience, education level, certificates and honors—was eventually transformed into variables for inclusion in the statistical models of later tasks in this study. The survey responses were categorized, cleaned and entered into a database. Information from open-ended questions was coded for analysis.

Findings

We tested the distribution of our survey sub-sample relative to the distribution of respondents in different types of classrooms, and were satisfied that it was sufficiently parallel to the original study population. In addition, the district administration reviewed the teacher characteristics and confirmed that the distribution of education and experience was in line with the overall population of elementary teachers in the district.

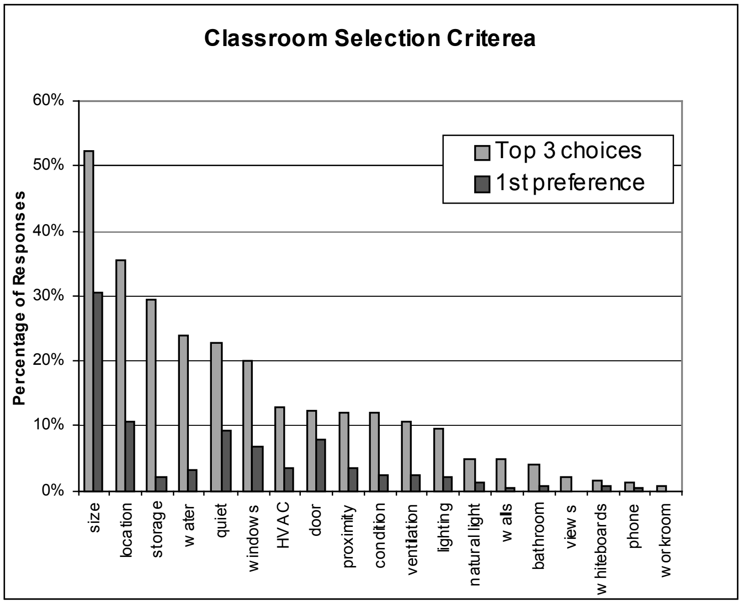
The results of the teacher survey on preferences and operation of classrooms suggest that daylighting and operable windows are indeed important to teachers, but tend to be secondary to their most pressing concerns, such as adequate classroom size, location, and water (hygiene) availability in classrooms. Acoustic, thermal and visual comfort, and adequate ventilation are all frequently listed as top priorities. Of course, teachers are likely to only express a preference for classroom characteristics that are available to them within their current context.

There are some important energy use challenges revealed in the survey that should be carefully considered by school designers and facility managers. Figure 2 reports on the frequency with which teachers make adjustments to the energy features of their classrooms.

Figure 1 shows the criteria that teachers would use to select a classroom. Windows were mentioned by 20% of the respondents as one of their top three priorities, after size, location, storage features, availability of water and quietness. Of course, teachers are likely to only express a preference for classroom characteristics that are available to them within their current context.

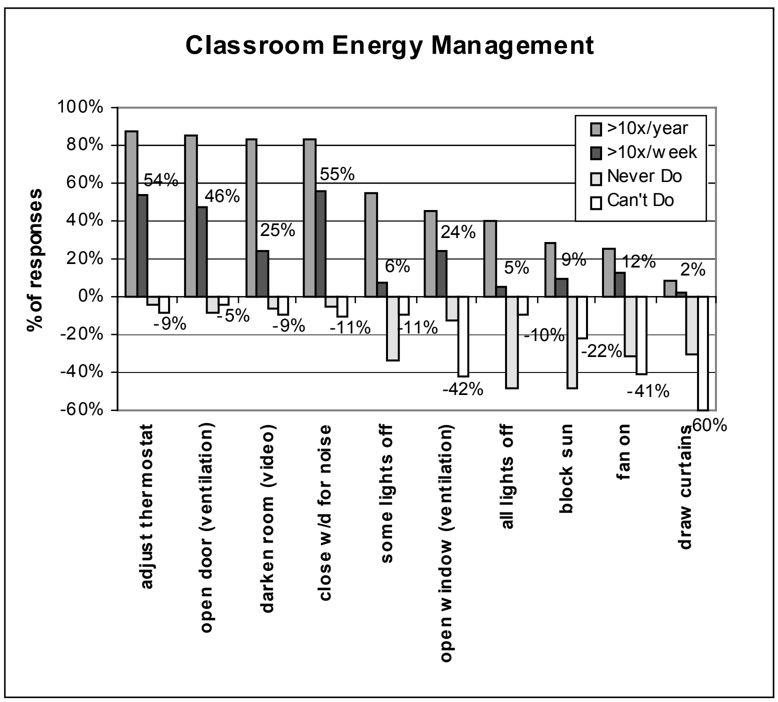
There are some important energy use challenges revealed in the survey that should be carefully considered by school designers and facility managers. Figure 2 reports on the frequency with which teachers make adjustments to the energy features of their classrooms.

Figure 1. Most Preferred Attributes of Classrooms



KEY:
Size = classroom size
Location = relative to school plan
Storage = amount of clsrm storage
Water = sink or tap water in clsrm
Quiet = quiet location
Windows = windows in clsrm
HVAC = good thermal conditions
Door = can close a door
Proximity = close to colleagues
Condition = surfaces in good repair
Ventilation = adequate ventilation
Lighting = good electric lighting
Natural Light = good natural light
Walls = lots of display space
Bathroom = close to bathrooms
Views = windows with a view
Whiteboards = white teaching wall
Phone = telephone in classroom
Workroom = close to workroom

Figure 2. Teachers' Energy Management of Classrooms

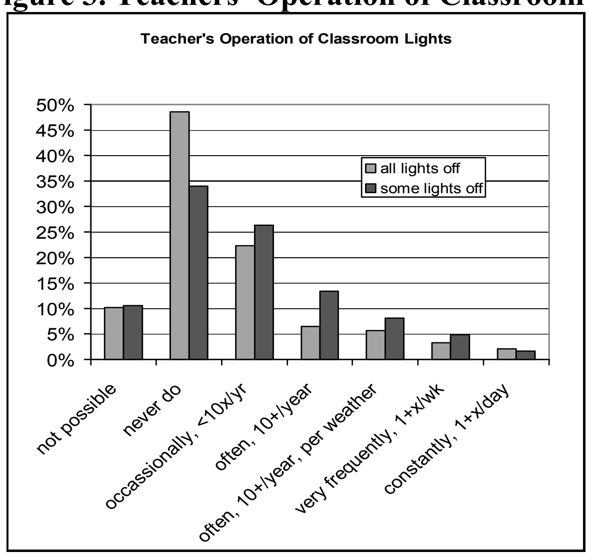


From the results shown in Figure 2, it is clear that Capistrano teachers are actively trying to increase the ventilation of their classrooms by opening doors, opening windows, and adding portable fans. Furthermore, 54% claim to be adjusting the thermostat at least once a week and 55% also claim to be closing windows or doors at least once a week specifically to control noise in the classroom, implying that they had previously opened them, most likely for ventilation. *This suggests that teachers' driving desires for good ventilation, thermal* *comfort and acoustic comfort tend to be in conflict with the options allowed by their physical environment.* Increasing ventilation is likely to also increase ambient noise in the classroom and/or reduce thermal comfort.

It was also noted that substantial energy can be wasted running heating or cooling systems while classroom doors and windows are open. Simply improving the efficiency of the heating and cooling systems will not solve this problem. Rather, given teachers' strong desire for more ventilation, classroom design should include systems that allow increased ventilation without increasing energy use for heating or cooling.

The teachers' responses on their use of lighting controls, as shown in Figure 3, suggest that a manual lighting control scheme has a likelihood of being operated by about one-half of the teachers in a school. A rough estimate suggests that this behavior might result in about 20-25% yearly lighting energy savings. This behavioral element should be factored into any proposed lighting control scheme. While automatic systems may be effective more often, their cost-effectiveness should be compared to manual systems that are occasionally operated by 50% of the teachers.

Figure 3. Teachers' Operation of Classroom Lights



Teacher Bias Analysis

The Teacher Bias Analysis further examined information from the Teacher Survey. The survey data were coded into variables and statistically analyzed in relation to two types of dependent variables: assignment to daylit classrooms and student performance on tests. The goal of the Bias Analysis was to discover if the original study had over-estimated the effect of daylight on student learning by not accounting for a potential assignment bias of "better" teachers to more daylit classrooms. For this discussion "better" teachers were defined as those who are responsible for faster learning rates in their students, as reflected in the rate of progress measured by standardized math and reading tests. Daylit classrooms were defined by the daylight code[2] assigned to each classroom in the original study.

[2] Quality and quantity of daylight distribution, on a scale of 0-5, where 0 = none and 5 = best.

Methodology

In order to study this question we needed to 1) find a way to identify potentially "better" teachers, 2) determine if the "better" teachers were being differentially assigned to more daylit classrooms and 3) determine to what extent the magnitude or significance of the daylighting effect would change if information that could predict teacher quality could be included in the model. We followed the following steps:

1. **Define Teacher Variables.** In order to create a metric for "better" teachers, we categorized the characteristics reported in the teachers' survey into eight variable codes: years of teaching experience; five levels of education (BA only without CLEAR[3] credential, BA only with CLEAR, BA and CLEAR with 16+ additional college credits, MA and CLEAR, MA and CLEAR with 16+ additional college credits); teachers with special certifications (i.e. gifted and talented education, bi-lingual, special education); teachers with special honors or awards (i.e. mentor teacher, county teacher of the year).
2. **Test for Collinearity.** Once we had defined the teacher characteristic variables, we looked to see if there were any significant correlations between these characteristics and the daylight conditions in the classrooms. Over one-half of the variable combinations (eight teacher characteristics x eight window characteristics[4]) showed some potential for correlation, but in no obviously consistent pattern. We concluded from this exercise that there was indeed some potential for an assignment bias. However, we also decided that a two-dimensional correlation analysis was not a sufficient tool to determine its magnitude or influence on the results of the multivariate regression models. Given that we were considering 50 explanatory variables, the potential for multidimensional interactions among variables was very high, and was best sorted out in the larger, multi-variate analysis.
3. **Decision to focus on daylight code only.** To simplify the analysis of collinearity in assignment bias, we chose to work with just the daylight code, instead of the multiple variables of the window code and the five skylight codes. The daylight code was the holistic code that combined the effects of window and skylight codes, and thus let us focus on one variable of interest, as we compared multiple models and influences in those models.
4. **Use daylight code as a dependent variable.** We ran a regression model with the daylight code as the dependent, or outcome, variable and the teacher characteristic variables as the independent, or explanatory variables. This model was run using only the surveyed teacher population. This model explained only 1% of the variation (R^2=0.01) in teacher assignment to daylit classroom. From this exercise, we concluded that the Capistrano Unified School District did not have any marked bias in the assignment of teachers to more daylit classrooms on the basis of any of the teacher characteristics studied..

[3] A CLEAR credential is the professional certification required of all California teachers after the first six years of teaching.

[4] Teacher characteristics included years of experience, education level, special certifications and awards. Window characteristics included window code (0-5), skylight type (5 types) operable (yes-no), and daylight code (0-5, synthesis of window and skylight codes).

5. **Re-run original model.** Our final step in the Teacher Bias Analysis was to re-run the original Capistrano student performance models with the teacher characteristic variables added to the list of potential explanatory variables. Teacher characteristic variables were added for the 42% of the population for which we had teacher surveys.

Findings

Table 1 and Table 2 show the findings of two student performance models, compared to the original models without the teacher variables. Even with the addition of the teacher characteristic variables into the original models, the daylight variable stayed highly significant in both cases. For the math model, with the outcome variable as the change from fall to spring math scores, the magnitude of the daylight effect decreased slightly. For the reading model, the magnitude of the daylight effect actually increased. In the case of the reading model, operable windows also remained a significant variable, and also increased slightly in magnitude.

Table 1. Change in Capistrano Math Model with Addition of Teacher Variables

New Model Capistrano, Teacher Analysis - 28-2 (Original population)	Math Daylight			Change new-old R^2	Old Model Capistrano, Original Analysis C17-md	Math Daylight		
Model R^2	**0.259**			**0.003**	**Model R^2**	**0.256**		
	B	Std. Error	p (Signif)	**B**		B	Std. Error	p (Signif)
(Constant)	9.045	0.464	0.000		(Constant)	8.026	0.407	0.000
Classroom characteristics					Classroom characteristics			
Daylight code	0.430	0.072	0.000	**-0.075**	Daylight code	0.504	0.067	0.000
Teacher characteristics								
Teacher 3	-0.933	0.248	0.000					
Teacher 5	-0.688	0.335	0.040					
Log yrs teaching	0.373	0.077	0.000					
Student characteristics					Student characteristics			
Grade 2	9.624	0.216	0.000	-0.088	Grade 2	9.711	0.215	0.000
Grade 3	5.949	0.220	0.000	0.018	Grade 3	5.931	0.219	0.000
Grade 4	1.802	0.216	0.000	-0.011	Grade 4	1.813	0.216	0.000
Absences unverified	-0.263	0.123	0.033	0.000	Absences unverified	-0.263	0.123	0.032
Absences unexecused	-0.029	0.014	0.043	-0.003	Absences unexecused	-0.026	0.014	0.069
GATE program	-1.191	0.222	0.000	0.045	GATE program	-1.236	0.223	0.000
Language program	0.488	0.205	0.017	-0.001	Language program	0.490	0.205	0.017
School characteristics					School characteristics			
School Pop-per 500	-0.995	0.000	0.000	-0.483	School Pop-per 500	-0.512	0.000	0.010

Three of the eight teacher characteristic variables were found to be significant in both models. (While the significant teacher variables here were consistent, they were not consistent in the models using window codes and skylight types as explanatory variables, nor were they consistent in later validation models that we ran of other sub-populations). With the addition of information about the teachers, the R^2 of the models increased, but only by a tiny amount, increasing their power of explanation by less than 1%. Furthermore, adding information about teacher characteristics for 42% of the population did *not* reduce the significance of the daylight variables. As might be expected, the magnitude shifted slightly; in one case down, in one case up.

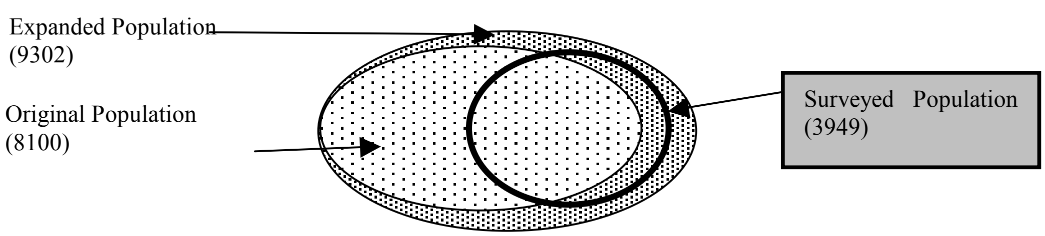
Table 2. Change in Capistrano Reading Model with Addition of Teacher Variables

New Model Capistrano, Teacher Bias Analysis - 28-2 (Original population)	Reading Daylight			Change new-old R^2	Old Model Capistrano, Original Analysis C17-rd	Reading Daylight		
Model R^2	**0.248**			**0.002**	**Model R^2**	**0.246**		
	B	Std. Error	p (Signif)	**B**		B	Std. Error	p (Signif)
(Constant)	3.009	0.303	0.000		(Constant)	3.025	0.298	0.000
Classroom characteristics					Classroom characteristics			
Daylight code	**0.475**	**0.086**	**0.000**	**0.011**	**Daylight code**	**0.464**	**0.085**	**0.000**
Operable windows	0.650	0.212	0.002	0.007	Operable windows	0.643	0.212	0.002
Teacher Characteristics								
Teacher 3	-0.917	0.288	0.001					
Teacher 5	-1.335	0.388	0.001					
Log yrs teaching	0.221	0.090	0.014					
Student characteristics					Student characteristics			
Grade 2	10.823	0.251	0.000	-0.037	Grade 2	10.860	0.251	0.000
Grade 3	4.368	0.255	0.000	0.069	Grade 3	4.298	0.254	0.000
Grade 4	0.944	0.252	0.000	0.008	Grade 4	0.937	0.252	0.000
GATE program	-1.432	0.257	0.000	0.020	GATE program	-1.452	0.257	0.000
LANG program	0.827	0.239	0.001	-0.011	LANG program	0.838	0.239	0.000

Thus, *we conclude that the strength of the daylight variable showed in the original analysis was not an inadvertent effect of a "teacher assignment bias."*

Additional analysis of sub-populations. One potential weakness in the findings above is that we had teacher characteristic information for less than one-half of the study population. We decided it would be a good test to re-run the models for just the population of students represented by teachers who responded to the Teacher Survey. That way, we could look at a validation model where 100% of the population had information about the teachers. This "surveyed population" model included 206 teachers and 3948 students, or about 50% of the original population (Figure 4). We also ran a set of models for an "expanded" population that included data on three additional schools excluded from the original analysis.

Figure 4. Surveyed, Original, and Expanded Population



We found that the shift in model study populations actually had a greater impact on the R^2 of the models (-.009 to +.017) than the addition of the teacher characteristic variables (+.001 to +.004) . Thus, we conclude that the selection of the study population is more likely to impact findings about the effect of daylight than is the addition of information about teachers.

We continue to believe in the importance of the addition of the teachers' characteristics to the model, both to access the potential for a teacher bias and to further refine the accuracy of the model. However, it is clear from this exercise that the study population is likely to have an even greater effect on the results. This once again argues for the importance of replicating the study in other districts, and preferably in widely differing geographic regions and cultural environments.

Grade Level Analysis

In this study task, we re-analyzed the original student test score data for both Capistrano and Seattle by grade level, instead of aggregating the data across the four grade levels (2-5). Our goal was to determine if this method would more accurately explain the relationship of student performance to daylighting. We tested for statistical significance and correlation, and we looked at any patterns discovered in the analysis.

Given the main objective of this task, it was hypothesized that daylighting may have a cumulative effect on student scores. This hypothesis would likely be true if a pattern of progressively stronger effects by grade level was observed in Seattle, where children typically remain under one school-wide daylighting condition. A comparative analysis for the test scores in the Capistrano school district, where students may change between high and low daylighting conditions during their stay at an elementary school, would corroborate our hypothesis if a minor or no cumulative effect of daylight was observed in that district.

Methodology

We re-ran the student performance regression models for both Seattle and Capistrano, this time allowing the daylighting effect to vary by grade level. This was achieved by adding grade level interaction variables for each variable in the model. This is statistically equivalent to running separate models, but simplifies the reporting and interpretation.

Interaction variables, between the grade level of the student and each explanatory variable, were created and added to the original Capistrano and Seattle models. As in the original study, the Capistrano model used the difference between fall and spring scores while Seattle's used the absolute value of the spring scores. Since information regarding teacher characteristics was available for the Capistrano school district, the teacher variables were also included in the Capistrano math and reading models to strengthen their explanatory power.

Findings

The data from our interaction models did not show a significant effect for the interaction variables between daylight and separate grade levels. This indicates that, for our study populations, we could not support the hypothesis that daylight has a different or cumulative effect on student performance by grade. We also found that allowing the results to vary by grade did *not* improve the accuracy of the models. The R^2 of the models changed slightly with the addition of the interaction variables. The largest increase in R^2 was 4% for the Seattle reading model. The other three models saw changes in R^2 of less than 1%, positive for two cases and negative for one. The daylighting effects remained highly significant even after the addition of the interactive variables. This indicates that daylight still provides a robust explanation of student performance in math and reading tests across all grades.

Furthermore, while we did find interaction effects between grade level and other variables, most notably the demographic variables, *we did not find a consistent interaction between grade level and a daylighting effect.* This was true in both Seattle and Capistrano.

From this exercise, we conclude that our original modeling approach, grouping all of the data for grades 2-5, was sufficiently accurate. We also note that we did not find any progressive effect for the daylighting variable, as postulated for Seattle, nor any other pattern of increased sensitivity to daylight related to the grade of the student.

Absenteeism Analysis

In this analysis, we used absenteeism and tardiness data available from the original Capistrano 1999 data set as dependent variables and evaluated them against the full set of explanatory variables from the original study, plus the new information on teacher characteristics. These models would allow us to assess whether daylighting or other classroom physical attributes potentially impacted student health or motivation, as measured by changes in student attendance. The hope was that student attendance could serve as a loose proxy for student health, even though there are other reasons for changes in student attendance besides health. It should be noted that our data did not allow us to distinguish reasons for absences or tardies.

In our earlier Capistrano study, we found that daylight was consistently associated with enhanced learning rates, and operable windows were associated (>95% certainty) with enhanced learning rates in three of the four models. In that original analysis, neither portable classrooms nor the presence or type of air conditioning had a consistent statistically significant effect.

Based on this finding we hypothesized that daylighting and operable windows might also be associated with a reduction in student absenteeism and tardiness in the Capistrano school district. If this hypothesis were true, operable windows and daylight, as explanatory variables, would appear to be significant and negative in a regression analysis with student absenteeism and tardiness as dependant variables.

In addition, we were also interested in the portable classroom and modular classroom variables, since many people have hypothesized that the glues and materials used in modular construction, combined with poor ventilation, may have a negative impact on student health. If portable or modular construction does indeed impact student health at a level where it might affect attendance, then we would expect to see these variables show up as significant in the regression analysis.

Methodology

A multivariate regression analysis was run, using the student characteristics, teacher characteristics, and school and classroom characteristics as independent, or explanatory variables against absenteeism data as the dependant, or outcome variable. A similar analysis was run with the same variables against the tardiness data as an outcome variable.

The study population was redefined to include all those students who attended at least 40 days at the same school. The students, however, were not required to have test scores. As a result, the study population shifted slightly, including more students who were not present for either the fall or spring tests, but excluding any students with missing attendance records. The resulting analysis population was 8808 students.

The absence variable was defined as a function of the sum of three fields in our data set: unverified absences, excused absences, and unexcused absences. Absences due to school function were not included. Only the sum of absences by type per student was available. We did not have information on the distribution of absences over time, or the reason for absences.

Findings

Student attendance, as measured by absences and tardies was not predicted by the daylight conditions of the classrooms in the Capistrano Unified School District. Likewise, other physical conditions of the classrooms were not found to be reliable predictors of student attendance. In general, only the demographic characteristics of the students were statistically significantly predictors of absenteeism.

From this exercise, we concluded that attendance data offer a very difficult outcome metric to use in trying to understand the effects of the physical environment on the performance of students, or the productivity of people in general. There are two basic reasons for this difficulty. First, attendance data can only be a loose proxy for the health of the student, since so many other events can cause a student to be absent or tardy besides health effects caused by the physical environment. Second, it is not a very sensitive metric. There is not a very big range in attendance values among students, with only about 10% of the student population showing much variation in number of days absent or tardy.

A summary of the findings from the absenteeism analysis is as follows:

- Daylighting variables were not significant indicators of absenteeism. Similarly neither operable windows nor portable classrooms variables were significant.
- Student demographic variables were the only reliable predictors of absenteeism
- Other physical characteristics of classrooms were not predictors of student attendance
- Attendance data are not particularly useful as a performance metric, since they provide meaningful variation for only 10% of the students in our fairly large samples (n= ~ 8800)

These findings are important because they do not support a number of claims that are currently being made about schools and student health. Specifically:

1. Portable classrooms are currently under investigation by a number of researchers for poor indoor air quality (Waldman 2001), which might reduce overall student health. Our study did <u>not</u> find that there was any significant association between portable classrooms and increased absenteeism among students. Nor did we find that being in a portable classroom in the Capistrano District was a predictor of reduced student performance.
2. Operable windows have been associated with a reduction in indoor air quality complaints (Callahan 1997). We did *not* find that the presence (yes-no) of operable windows was significantly associated with any improvement in attendance among elementary school students. We did however, find that the presence of an operable window was associated with improved student performance.
3. Claims have been made that daylit schools are associated with improved attendance among students (Nicklas 1997). We did *not* find that increased daylight in classrooms was associated with better attendance.

Summary

Overall, the strength of the daylight variable in predicting student performance stands out sharply across all of these re-analysis efforts. The addition of more information to the models did very little to change the predicted impact of the Daylight Code on student performance.

Only the exercise to link the Daylight Code to student attendance was unsuccessful. This is also an extremely important finding, since it contradicts so many claims have been made about the health effects of daylight or other indoor environmental conditions, as reflected in absenteeism rates of building occupants. In this study, in this particular school district, we did not find that any of the physical attributes that we had available to classify the classrooms could be linked significantly with student attendance.

It is also very clear from these efforts, as we re-analyzed the original data sets with additional information, that the findings of these models are much more strongly dependant upon the particular population studied in the analysis than upon the subtleties of all the variables included in the models. Thus, we conclude that it will be much more informative to try to replicate this study with a completely different population, at a different school district, than it would be to continue to try to refine the models and with further detail in the explanatory variables. This process has been informative as a sensitivity analysis and methodological study.

Acknowledgments

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