Effects of school design on student outcomes

C. Kenneth Tanner
School Design and Planning Laboratory, Department of Workforce Education, Leadership, and Social Foundations, University of Georgia, Athens, Georgia, USA

Received April 2008
Revised September 2008
Accepted December 2008

Abstract

Purpose – The purpose of this study is to compare student achievement with three school design classifications: movement and circulation, day lighting, and views.

Design/methodology/approach – From a sample of 71 schools, measures of these three school designs, taken with a ten-point Likert scale, are compared to students' outcomes defined by six parts of the Iowa Test of Basic Skills (ITBS): Reading comprehension, Reading vocabulary, Language arts, Mathematics, Social studies, and Science. Data are tested through reduced regression analysis, where the difference between R^2 of the reduced regression is compared to the R^2 of the full regression. This result, in each case, is defined as the effect of the school's physical environment on students' outcomes represented by achievement scores on the ITBS.

Findings – Significant effects are found for Reading vocabulary, Reading comprehension, Language arts, Mathematics, and Science.

Practical implications – The study's findings regarding movement and circulation patterns, natural light, and classrooms with views have implications for designing new schools or modifying existing structures. They are especially important to school leaders, educational planners, and architects who engage in programming for educational facilities.

Originality/value – This study is part of original research efforts at the University of Georgia, USA. Since 1997, the focus of research in the University of Georgia's School Design and Planning Laboratory (SDPL) has been the measurement of the impact of the school's physical environment on aspects of affective, behavioral, and cognitive learning. All SDPL research has been quantitative in nature, where measures of the physical environment were compared to measures of student outcomes. There are two immediate values to these studies: educational leaders may use the findings to assess their existing school facilities and determine where improvements will have the greatest impact, or planners may use the findings to guide architects in the design and construction of new educational facilities.

Keywords Schools, Design, Students, Architecture, United States of America

Paper type Research paper

One purpose of this study was to identify and test school designs that possibly influence student outcomes. Another purpose was to provide a straightforward research method that could be replicated by students of educational planning and architecture. Numerous school design components have been identified as noted in the related literature review in this article and others in this issue. Only a few have been tested regarding validity and reliability. The question remains: can the physical environment's impact on student outcomes be measured according to a defensible set of hard data? The basic assumption was that there exists a chance that the measurement task might be accomplished; and effects might possibly be shown. It was hypothesized that the study would provide a clear example of how to conduct research

Journal of Educational Administration
Vol. 47 No. 3, 2009
pp. 381-399

0957-8234
DOI 10.1108/09578230910955809

on the relationships among school design variables and student outcomes through the use of hard data and quantitative methods.

Concern has been raised in the literature and among professional architects and educational planners regarding the degree to which the school's physical environment, defined as various classifications of design items, influences student outcomes, especially behavior and achievement. With this concern as a guiding principle, this study, accompanied by its uncertainties, was conducted to seek an answer to how the design of a school might influence student achievement.

As a researcher, I assumed that it was important to contemplate the interaction between people and their environments since we are constantly interacting with physical things in places for learning and living. Since 1997, our research at the University of Georgia's School Design and Planning Laboratory (SDPL) has emphasized places and spaces for learning, including such categories as color, light, acoustics, movement, circulation, views, design, scale, location, learning neighborhoods, and outdoor learning (Tanner and Lackney, 2006). Our correlation research on the physical environment has occasionally suggested that areas such as lighting and acoustics influenced student outcomes, while many other areas, especially color and school location, remained totally elusive. Not until we expanded the sample size, refined the validity and reliability of our instruments, and collected a larger sample of hard data did we begin to discover some possibly defensible effects. The work at SDPL has been immediately rewarding for several public and independent school systems in the United States by providing hard evidence that certain aspects of school design directly affect student outcomes. In the realm of expanding and explaining the physical environment's relationship to learning, it was important to learn if the school's physical environment influenced student achievement; and if it did, which designs were most significant.

Definition of the physical environment in this study

Efforts to refine ideas about the physical environment and transfer them into valid instrumentation for measurement limited themselves to three basic design patterns or categories, movement and circulation, day lighting, and views. The choice of three categories was dictated by constraints of sample size and regression analysis methods. Several authors and researchers, as indicated in the following analysis, have investigated these categories, some from a qualitative perspective.

The qualitative aspect of this study began with the concept of a language that would describe and explain how a building and environment interact with students. The word "patterns" refers to components, items, and design characteristics interchangeably. This study was about design patterns that were initiated by the author of *The Timeless Way* (Alexander, 1979). According to Alexander (1979), a building will be alive to the extent that it is governed by the timeless way. The concept of the timeless way includes a process that brings order out of us. The quality of a building is objective and precise, and it is given its character by patterns of events that continue to happen there. These patterns of events interlock with certain geometric patterns in space, and people can shape buildings for themselves by using pattern language. It gives each person who uses this specialized language power to create an infinite variety of new and unique buildings, just as our ordinary language gives us the power to create an infinite variety of sentences. Three sets of patterns are presented below.

Patterns of movement and circulation

One of the first concerns in SDPL research was places and spaces where people were free to move about without feeling they were confined or in a crowded environment. Therefore, movement and circulation became our very first category for research in 1997, and has continued to be of interest. Movement and circulation patterns as described in this study and initially detailed in *A Pattern Language* (Alexander *et al.*, 1977), include the following:

- *Outside walkways*. Paths, arcades, or promenades linking main areas; ideally placing major activity centers at the extremes.
- *Pathways*. Clear and comfortable passages allowing for freedom of movement and orientation, with signage, among and within structures.
- *Public areas*. Spaces that foster a sense of community (unity and belonging) such as an auditorium and a dining area. These are inviting and comfortable settings and include ample lighting.
- *Reference*. The main building has an obvious point of reference among the school's buildings in which paths and buildings connect.
- *Outdoor spaces*. These places are defined as learning areas, and wings of buildings, trees, hedges, fences, fields, arcades, or walkways may surround them.

Outside walkways are paths, arcades, and covered walkways at the edge of buildings. Walkways play a vital role in the way that people interact with buildings, yet there is some essential overlap between walkways and pathways because both have goals such as benches for waiting outside for transportation or chairs inside near certain offices or classrooms, water fountains, clusters of plants to break up a long corridor, windows strategically located to give natural light and provide views, and archways to give the effect of inviting people into certain areas. Pathways should have goals no more than 100 feet apart (Alexander *et al.*, 1977, p. 588). Ideally in developing pathways, architects should avoid the use of corridors and passages. Instead, they may use public rooms and common spaces for movement and for gathering, placing the common rooms to form a chain, or loop, making it possible to walk from room to room, with private rooms open directly off these public rooms. In every case, the indoor circulation from room to room gives a feeling of great generosity, passing in a wide and ample loop around the house (school), with views of fireplaces and great windows (pp. 630-61). Here, Alexander *et al.* (1977) referred to a house. Consider replacing the words house with school, and fireplaces with exhibits of students' work and accomplishments. It is this type of word swapping that led the SDPL researchers to the idea of a pattern language for schools. Regarding pathways that flow through rooms, "[. . .] movement between rooms is as important as the rooms themselves" (Alexander *et al.*, 1977, p. 628). Long sterile corridors set the scene for everything bad about modern architecture, according to Alexander *et al.* (1977, p. 633).

Public areas are places that foster a sense of community (unity and belonging). Our research includes a wide variety of public spaces, but this article is limited to the discussion of auditoriums, dining areas, and outdoor spaces. Public areas are inviting and comfortable settings including ample lighting. Positive outdoor space and public outdoor rooms are places where people hang out, comfortably, for hours at a time (Alexander *et al.*, 1977, p. 349). In outdoor spaces, people always try to sit or stand where they can have their backs protected, looking out toward larger openings, beyond the space immediately in front of them. This pattern is entitled *Hierarchy of Open Space* (Alexander *et al.*, 1977). Outdoor spaces which are merely "left over" between buildings will generally not be used, according to Alexander *et al.* (1977, p. 518).

Reference is highly important, and according to Alexander *et al.* (1977), the placement of the main entrance constitutes the single most important step taken during the evolution of a building plan. The main building complex has an obvious point of reference among the buildings in which paths and buildings connect. From the reference area, we expect to find a main circulation space, which opens directly from the main entrance, or reference area. Reference is enhanced by defining the central position, main building, since "a complex of buildings with no center is like a man without a head" (Alexander *et al.*, 1977, p. 486).

In addition to the work discussed above, Sommer (1969) made significant contributions to this field in the areas of personal and social distance. A crowded school, ignoring personal and social distance, has a negative influence on student outcomes. Thus:

> It appears as though the consequences of high-density conditions that involve either too many children or too little space are: excess levels of stimulation; stress and arousal; a drain on resources available; considerable interference; reductions in desired privacy levels; and loss of control (Wohlwill and van Vliet, 1985, p. 108).

Student population density may be viewed through psychological implications by studying territoriality of place. Since the school is a social system within the cultural environment, social distance as it relates to crowding and density is a function of school design and decision making. Another aspect of density is the lower middle range for social distance in man and woman. Sommer (1969) completed several studies on small group ecology and found that when people are at 3.5 feet apart, they shift their seating positions in favor of "side by side" as opposed to "across" from each other (p. 66). Seven feet appears to be the maximum diameter for social distance. Sommer's finding correlates with the seven feet (2×3.5 feet) needed for social distance in man and woman as recommended by Banghart and Trull (1973). This appears to be the amount of space needed when a person is seated, which is approximately 20 square feet (multiplying the golden ratio π by the radius squared $(3.5 \text{ feet})^2 = 18.82$ square feet). Factor in the need to circulate and the amount of needed space increases. When considering cultural backgrounds, this amount of space will probably vary, since this research was limited to the USA averages.

Space in a room delivers a silent message to students, where the flow and shift of distance between people is a large part of the communication process (Duncanson, 2003; Hall, 1959). Special attention should be given to circulation classifications that permit student traffic to flow quickly from one part of the building to another. Movement within the school should not consist of a progression of individual experiences but instead be a conscious and perceptible environmental exchange; and complex structures that cause crowding should be avoided. Movement within a school may be an important supporter of learning. Pathways free of obtrusions between activity areas and classrooms improve utilization of learning spaces. Public rooms and common rooms may be substituted for traditional hallways and private rooms may open directly off public rooms.

Numerous design classifications have been developed and tested as part of the original instruments for assessing movement and circulation in the schools (Tanner and Lackney, 2006). Andersen (1999) conducted research on ten movement and circulation classifications, Ayers (1999) studied nine areas, and Yarborough (2001) investigated 17. Correlations found in these studies among movement and circulation classifications and students' outcomes were positive and statistically significant; but there was no defense as to the "effects" of movement and circulation patterns on student achievement.

Patterns of day lighting

Day lighting in schools gained many supporters when the definitive study by the Heschong Mahone Group (1999) proved natural light to be significant in student achievement. Well before the 1999 quantitative study, Alexander *et al.* (1977), through qualitative methods, offered *Indoor Sunlight* and *Tapestry of Light and Dark* as evidence of the need for natural lighting in buildings. From these two patterns, we note that rooms should face south to allow for natural light, except art rooms, which should face north to ensure consistent natural light. The concept of tapestry of light and dark is defensible in schools where transition areas and pathways may be slightly darker than classrooms. Research efforts at the SDPL have generated two categories for this analysis:

(1) *Natural light in classrooms*. Classrooms have light from windows, skylights, borrowed light, reflected light, and artificial sources.

(2) *Sources of light*. Artificial light plus natural light from the outside, preferably on two sides of every room is ideal for student learning and comfort.

Light is the most important environmental input, after food and water, in controlling bodily functions (Wurtman, 1975). Lights of different colors affect blood pressure, pulse, respiration rates, brain activity, and biorhythms. Full-spectrum light, required to influence the pineal gland's synthesis of melatonin, which in turn helps determine the body's output of the neurotransmitter serotonin, is critical to a child's health and development (Ott, 1973). To help reduce the imbalances caused by inadequate exposure to the near ultra-violet and infrared ends of the spectrum, full-spectrum bulbs that approximate the wavelengths provided by sunshine should replace standard fluorescent and tungsten bulbs (Hughes, 1980). There is ample evidence that people need daylight to regulate circadian rhythms, a natural biological function discussed in the pattern entitled *Wings of Light* (Alexander *et al.*, 1977, p. 527). Poorly lit and windowless classrooms can cause students to experience a daily form of jet lag; furthermore, forms of florescent lighting may affect some students and teachers negatively by causing mild seizures (Tanner and Lackney, 2006, p. 270).

In a study of over 21,000 students, controlled for socioeconomic status (SES), in California, Washington, and Colorado, the Heschong Mahone Group (1999) found that students with the most day lighting in their classrooms progressed 20 percent faster on mathematics and 26 percent faster on reading tests over a period of one year than students having less daylight in their classrooms. Similarly, students in classrooms having larger window areas were found to progress 15 percent faster in mathematics and 23 percent faster in reading than students in classrooms having smaller windows. Day lighting, provided from skylights, distinct from all the other attributes associated with windows, had a positive effect (p. 62). Windows are the most common spaces bringing natural light into the learning environment and invite the outdoors inside.

Medical doctors reported a biological need for windows in a study by Kuller and Lindsten (1992); this research suggested that windowless classrooms should be avoided for permanent use. Rather than windows being a distraction and disrupting the learning process, an argument often used from the narrow conventional wisdom or best practices side of reasoning, they provide a necessary relief for students. This relief is associated with window gazing and is less consuming than the focused attention used to draw pictures or doodle in a notebook. It is much easier for students to refocus their attention back on the teacher when engaged in tasks requiring soft attention (such as window gazing) rather than those requiring more focused attention. One of the most important functions of a window is to put the student in touch with the outside. If the windowsill is too high, then this is impossible (Alexander *et al.*, 1977).

Patterns of views

Classroom windows (with views) overlooking outside life was hypothesized as a positive aspect of the school environment at the beginning of the first research efforts of the SDPL. From work completed over several years, we developed several valid descriptors for patterns of views. The reliability analysis for this study reduced the larger pool of patterns of views (Tanner and Lackney, 2006) to the five listed below:

(1) *Views overlooking life*. Students need vistas to the outside world that are not overlooking a wall or parking lot.

(2) *Unrestricted views*. Windows should be available within the classroom, and when glare is not a problem, without obstructions such as posters and curtains.

(3) *Living views*. From the classroom, not necessarily from the sitting position, students should be able to view some indoor spaces and outdoor spaces such as gardens, wildlife, fountains, mountains, and the sky.

(4) *Functional views*. Doors and windows should allow the student to easily see at least 50 feet outside the classroom.

(5) *Green areas*. It is important for the student to see outside spaces, close to the school building, having trees, grass or gardens. There should be few views of parking lots and roads.

It is important to make the best use of a view by ensuring that it is taken from places of transition and not straight on. Furthermore, views should not necessarily be visible from the places where people sit (Alexander *et al.*, 1977, p. 643). This concept is described as the Zen view (Alexander *et al.*, 1977). This concept is important for classrooms where the student needs to see outside but not necessarily have a commanding view. Views of at least 50 fe*et al*so enable students to rest their eyes (Nair and Fielding, 2005).

Summary of background information on the physical environment

There are numerous fine points to be associated with the descriptions of movement and circulation, day lighting, and views in the above sections. Highlights are all that are covered, but the reader is encouraged to carefully study the rich literature offered by various works cited. Freedom of movement and circulation among and within structures was a key aspect of this research project. There are many minute items such as signage, outdoor spaces, and points of reference that support this design pattern. Having daylight in a classroom is vital to the student's learning processes. Natural light and windows on two sides of the classroom allow for ease of viewing beyond the room's four walls, and for resting the eyes. When people have a choice between rooms with windows on one side and rooms with windows on two sides, they gravitate to the rooms which are lit on two sides (Alexander *et al.*, 1977, p. 747). Unrestricted views of nature add to the well being of students and teachers. Looking into a parking lot or the wall of another building is undesirable.

Methods

Three sections of instruments developed to assess school design provided the foundation for school design data collection for this study. To review the comprehensive set of instruments developed by the SDPL, see contributions made by Andersen (1999), Ayers (1999), Tanner (2000, 2006) and Yarborough (2001). The design variables based on the above literature review were refined in this study through reliability analysis to include the 13 items within three classifications.

The instrument included a ten-point Likert scale, where items were scored (measured) from 0 to 10. Assigning a "0 or blank" to a specific item indicated that the item was not present, while a score of ten indicated the highest degree of presence of the design component found in the school's physical environment. This score should be considered as the proportion of classrooms or learning spaces with a given characteristic or design pattern. Scores for each of the three sub scales were assumed to be additive. The instrument may be used to evaluate existing schools (post-occupancy evaluation) or it may be employed to influence the concept design phase of school facilities planning.

Given the 13 design items that passed the reliability test, a school's total score might be translated into ratings such as those found in Table I. A school facility might receive the following ratings based on its total score: 90-100 percent (superior), 80-89 percent (good), 70-79 percent (adequate), or less than 70 percent (inadequate).

The original intent of the instrument was for its application only by people trained in educational planning with knowledge of the various items in its contents. However, as refinement has continued for several years, and validity increased, the small instrument found in Table II might be used for general distribution to accomplish data

Total score for 13 items	The school's design rating
117-130 Points	Superior design
104-116 Points	Good design
91-103 Points	Adequate design
<90	Inadequate design

Table I. Design ratings based on scores of the 13 items found in Table II

Instructions: Please score the 13 design patterns on the scale (1 to 10) as defined in each section. If the school does not have a specific feature, the score is "0" for that item. Place each score at the left of individual items. Design includes the way the schoolhouse is made, how it is arranged, and how the outside areas, near the school, complement the curriculum. Each scale measures the school's learning environment, allowing for the recording of the "degree" to which a design component is present.

Total Score: _________________ School Name:___________________________

Movement and Circulation

The school's design may be judged regarding its ability to enable students and teachers to enter and move freely within and around a facility.

1______Outside Walkways: Paths or promenades linking main areas; ideally placing major activity centers at the extremes.

Ambiguous   Distinct
< -- >
0 1 2 3 4 5 6 7 8 9 10

2_____Pathways: Clear and comfortable passages allowing for freedom of movement and orientation, with signage, among and within structures.

Ambiguous   Clear
< -- >
0 1 2 3 4 5 6 7 8 9 10

3_____Auditorium (Public Area that fosters a sense of community (unity and belonging) that is inviting, comfortable, and includes ample lighting.)

Poor   Excellent
<-- >
0 1 2 3 4 5 6 7 8 9 10

4____Dining Area (Public Space that fosters a sense of community (unity and belonging) that is inviting, comfortable, and includes ample lighting.)

Poor   Excellent
<-- >
0 1 2 3 4 5 6 7 8 9 10

5_____Reference: The main building has an obvious point of reference among the school's buildingsin which paths and buildings connect.

Obscure   Obvious
< -->
0 1 2 3 4 5 6 7 8 9 10

(*continued*)

Table II.
Components of the design appraisal scale

6_____Outdoor Spaces : Places which are defined as learning areas (They may be surrounded by wings of buildings, trees, hedges, fences, fields, arcades or walkways).

Non-existent Plentiful

< -- >

0 1 2 3 4 5 6 7 8 9 10

Day Lighting

7_____Natural Light in Classrooms: Light in classrooms from windows, skylights, borrowed light, reflected light, and artificial sources.

No Mixture of Natural Light Ample Mixture of Natural Light

< -- >

0 1 2 3 4 5 6 7 8 9 10

8_____Sources of Light: Artificial light plus natural light from the outside, preferably on two sides of every room.

Poor Excellent

< -- >

0 1 2 3 4 5 6 7 8 9 10

Views

9_____Views Overlooking Life: Vistas for students to the outside world (not overlooking a wall or parking lot).

None Numerous

< -- >

0 1 2 3 4 5 6 7 8 9 10

10_____Unrestricted Views: Windows in use, when glare is not a problem, without obstructions such as posters and curtains.

Sparse Ample

< -- >

0 1 2 3 4 5 6 7 8 9 10

11______Living Views: Views of indoor and outdoor spaces (gardens, wildlife, fountains, mountains, etc.)

Sparse Ample

< -- >

0 1 2 3 4 5 6 7 8 9 10

12_____ Functional Views: Doors and windows that allow the student to easily see at least 50 feet outside the classroom.

Inadequate Adequate

< -- >

0 1 2 3 4 5 6 7 8 9 10

13_____ Green Areas: Outside spaces, close to the school building, where trees, grass or gardens may be seen (few views of parking lots and roads).

Non-existent Plentiful

< -- >

0 1 2 3 4 5 6 7 8 9 10

Table II.

collection (e.g. a mail-out questionnaire). Caution is appropriate; and it should be noted that one comprehensive, valid descriptor should be added per item (see the review of literature for descriptors). Descriptors strengthen the responder's depth of understanding regarding pattern language and concept design (Tanner and Lackney, 2006; Alexander, 1979; Alexander *et al.*, 1977).

From a pool of design components that the SDPL identified and analyzed since 1997 (Tanner and Lackney, 2006; Tanner, 2000, 2006), an item to scale analysis (Cronbach's α) was performed on 34 selected components matching three sub scales: movement and circulation (26 items), day lighting (two items), and views (six items). The purpose of the reliability analysis (Table III) was to reveal an index of dependability for each of the three sub-scales employed in this study. The total number of items was reduced from 34 to 13. The original 34 items may be found in Tanner and Lackney (2006, pp. 295-306). In each set of items, the reliability coefficient was greater than 0.64, which is classified as "good." Acceptable reliability standards, according to Cicchetti (1994), for clinical significance is as follows: $r < 0.40$ (poor), $0.41 \leq 0.60$ (fair), $0.61 \leq 0.75$ (good), and > 0.76 (excellent).

Dependent variables defined by the ITBS

The Iowa Test of Basic Skills (ITBS) (2008) was constructed to describe a student's developmental level, identify areas of relative strength and weakness in subject areas, and monitor year-to-year growth in the basic skills. It has been in use since 1935. The rationale for selecting the reading comprehension, reading vocabulary, language arts, mathematics, social studies, and science sections of the ITBS for this study was that a collection of tests in several subject areas, all of which have been standardized, makes it possible to formulate research-based statements about a student's relative position on a standard scale. Norms serve as a basis for comparison and allow one group of students to be compared with another group. Furthermore, norms allow schools, the unit of analysis in this study, to be compared. These comparisons provide an opportunity to look at achievement levels in relation to a nationally representative group of students or schools.

Data collection

Design scores for this analysis were retrieved from the SDPL's data bank, which maintains valid, reliable, and refined information on 71 rural and suburban elementary schools (*k*-6). The students' test data represented over 10,650 fifth grade students in 19 Georgia school districts[1].

Table III. Reliability analysis for the three sub-scales

Category	Cronbach's α	Cronbach's α standardized	No. of selected items[a]	No. of original items
Movement and circulation	0.789	0.817	6	26
Day lighting	0.643	0.646	2	2
Views	0 .820	0.820	5	6

Note: [a]See Table II to identify each sub-scale of design components employed in this study

School design information as found in Table II was observed during site visits requiring approximately two hours each. The purpose of each visit was to complete a guided tour of the educational facilities and outdoor learning environments. A comprehensive tour was necessary to accurately complete the design assessment instrument for each facility. Three researchers trained in school design and assessment conducted each site visit (one researcher per site). That same researcher completed the instrument for each facility within one hour of concluding the visit and before beginning assessment of another school. To minimize bias, all the site visits were completed before the ITBS data were obtained from the Georgia Public Education Report Card for Parents. The data bank for this study, in addition to the design evaluation per school, included the following variables: achievement data (Reading comprehension, Reading vocabulary, Language arts, Mathematics, Social studies, and Science fifth grade ITBS scores per school), and a proxy for SES (which was the percentage of students receiving free and reduced cost school lunch).

Research question and assumptions

The research question for the analysis was: what are the effects of the school's physical environment, as defined in the assessment scale, on fifth grade students' ITBS scores in six categories: reading comprehension, reading vocabulary, language arts, mathematics, social studies, and science? Reliability analysis and reduced regression models were employed to compare student achievement as measured by the ITBS (the dependent variables) with the three well-defined design variable sets representing the physical environment (independent variables).

The primary hypothesis for this study was that places and spaces where students learn make a difference in what and how much they learn. Several assumptions guided the study:

- The school's physical environment may be classified according to sets of design patterns that are measurable on a Likert scale in terms of the degree to which they exist in each school.
- Validity and reliability can be established for an instrument that measures a certain design pattern's existence in a given school setting.
- The ITBS is a valid and reliable measure of cognitive learning.
- This study was classified as "non experimental," raising a concern for the explanation variables. We already know that SES accounts for the majority of the variance in student achievement studies; therefore, any attempt to document additional variance representing the physical environment is certainly worth the risk.

Statistical assumptions

- Regression analysis is an appropriate descriptive technique assuming: on the average, errors balance out; independent variables are not random; uncontrolled variables are approximately the same for each observation; there are no autocorrelations among uncontrolled variables; and the design classifications are linearly independent.
- The regression technique can determine relationships between academic achievement and the physical environment, thereby possibly explaining the

effect size (the influence of the physical environment on student achievement). While, the effect size does not explain causality, repeated studies yielding similar effects can approach this elusive relationship.

- Overall, the regression analysis applied in this study is robust in the presence of departures from assumptions, except for measurement errors.

Analysis of the data

Effects of school design on ITBS scores were determined by comparing the proportion of variance explained by the full regression models and the reduced models, that is, taking the difference between R^2 of the full regression and the R^2 of the reduced regression models. The reduced regression included the six ITBS variables (dependent variables) and a proxy for SES, which served as the independent variable. SES is frequently used as a predictor of differences in achievement (Ferguson, 2002). In this study, the R^2 values ranged from 45 to 69 percent (Table IV), indicating the amount of variance associated with SES in the six dependent variables. Note in Table IV that all the R^2 values indicated the correlations between SES and the ITBS scores were significantly different from "0" ($\alpha = 0.000$). The R^2 values for the each of the ITBS categories in Table IV are matched with the full regression components described later in the article.

Table V shows a comparison between the full and reduced regression models for each of the six ITBS categories. The reduced regression per ITBS category is presented in Table IV. SES was the only significant contributor to the variance in ITBS scores among independent variables, including the number of years of teaching experience, education levels of the teachers, and ethnicity. These variables were included in the initial analysis because some of the SDPL researchers insisted that teaching experience and education could have been significant enough to be detected in this analysis. Ethnicity, in all likelihood, was imbedded in the SES variable. Tables AI-AVI in the Appendix show the detailed calculations for each full regression and R^2 change (effect). All effects were significant (F change in Tables AI-AVI) except the 1.7 percent effect determined for Social studies ($\alpha = 0.298$). The findings were that the school design classifications of movement and circulation, day lighting, and views, indicated significant effects on Reading comprehension, Reading vocabulary, Language arts, Mathematics, and Science.

Further analysis, as presented in Tables VI and VII, reveals exactly which design classification influenced ITBS scores. Analysis up to this point has indicated significant effects among the design classifications and ITBS scores. Table VI reveals exactly where effects were.

Table VII provides a detailed analysis supporting Table VI. Note that SES significantly influenced all of the ITBS components. This is not surprising, since SES represents a bundle of abilities and attitudes that a student brings to school, and accounts for variance in student achievement more than any other variable. From Table IV, note the R^2 for Reading comprehension of 0.691 ($\alpha = 0.000$). Table VII shows that movement and circulation have a significant effect on Reading comprehension, while the other two variables, day lighting and views, did not show statistically significant effects ($\alpha = 0.099$ and 0.168, respectively). For this sample, movement and circulation were most important in explaining score variance, since four of the ITBS categories had significant effects

Source	Dependent variable	Tests of between-subjects effects Type III sum of squares	df	Mean square	F	α
Corrected model	readcomp	4259.986[a]	1	4259.986	154.260	0.000
	readvoc	7408.227[b]	1	7408.227	128.186	0.000
	larts	3264.703[c]	1	3264.703	57.288	0.000
	math	8233.217[d]	1	8233.217	147.013	0.000
	socstud	6368.116[e]	1	6368.116	154.408	0.000
	science	8695.068[f]	1	8695.068	117.327	0.000
Intercept	readcomp	37414.994	1	37414.994	1354.848	0.000
	readvoc	38186.184	1	38186.184	660.741	0.000
	larts	42436.846	1	42436.846	744.663	0.000
	math	54273.822	1	54273.822	969.120	0.000
	socstud	48306.369	1	48306.369	1171.284	0.000
	science	56434.027	1	56434.027	761.492	0.000
SES	readcomp	4259.986	1	4259.986	154.260	0.000
	readvoc	7408.227	1	7408.227	128.186	0.000
	larts	3264.703	1	3264.703	57.288	0.000
	math	8233.217	1	8233.217	147.013	0.000
	socstud	6368.116	1	6368.116	154.408	0.000
	science	8695.068	1	8695.068	117.327	0.000
Error	readcomp	1905.479	69	27.616		
	readvoc	3987.716	69	57.793		
	larts	3932.170	69	56.988		
	math	3864.219	69	56.003		
	socstud	2845.715	69	41.242		
	science	5113.580	69	74.110		
Total	readcomp	173612.000	71			
	readvoc	136808.000	71			
	larts	230189.000	71			
	math	221082.000	71			
	socstud	210246.000	71			
	science	229134.000	71			
Corrected total	readcomp	6165.465	70			
	readvoc	11395.944	70			
	larts	7196.873	70			
	math	12097.437	70			
	socstud	9213.831	70			
	science	13808.648	70			

Notes: [a]$R^2 = 0.691$ – Reading comprehension (readcomp); [b]$R^2 = 0.650$ – Reading vocabulary (readvoc); [c]$R^2 = 0.454$ – Language arts (larts); [d]$R^2 = 0.681$ – Mathematics (math); [e]$R^2 = 0.691$ – Social studies (socstud); [f]$R^2 = 0.630$ – Science (science)

Table IV. The reduced regression model – ITBS scores with SES

from this variable. Day lighting influenced variance in Reading vocabulary and Science scores more than in the other four ITBS categories. Classrooms having views significantly influenced variance in Reading vocabulary, Language arts, and Mathematics.

Discussion

For each section of the ITBS, except Social studies, as indicated in Tables VI and VII, there was at least one significant R^2. This result implies the importance of each of the three classifications of school design patterns. Movement and circulation patterns significantly influenced the variance in Reading comprehension, Language arts, Mathematics, and Science scores. Spaces allowing freedom of movement and circulation correlated with better test scores, which parallels Wohlwill and van Vliet's (1985) implication that a crowded school has a negative influence on student outcomes.

Day lighting did not influence the variance in Mathematics scores in this study as significantly as it did in the Heschong Mahone Group's study (1999). However, it did significantly affect the variance in Science and Reading vocabulary scores.

Patterns of views were probably the most surprising set of variables in this study. There exists little quantitative evidence on this topic in the literature. Views significantly influenced the variance of Reading vocabulary, Language arts, and Mathematics. Apparently, the Zen view (Alexander *et al.*, 1977) is important for classrooms where the student needs to see outside, but not necessarily have a commanding view. The provision for the students to rest their eyes by allowing a minimum view of at least 50 feet (Nair and Fielding, 2005) is supported by this study's significant findings regarding patterns of views.

If this study is replicated with parallel findings, then a case can be built that the documented significant effects were not just random occurrences. This research effort puts forth the concepts, rationale, and methods to complete other related studies designed to clarify just how much influence the physical environment has on student learning. According to results from the sample used in this study, the places and spaces where students learn make a difference in their achievement levels.

ITBS scores	Full Reg. R_F^2	Reduced Reg. R_R^2	Effect $R_F^2 - R_R^2$	α
Reading comprehension	0.778	0.691	0.087	0.000
Reading vocabulary	0.703	0.650	0.053	0.012
Language arts	0.550	0.454	0.096	0.005
Mathematics	0.760	0.681	0.080	0.000
Social studies	0.708	0.691	0.017	0.298
Science	0.699	0.630	0.069	0.003

Note: See Appendix for detailed calculations

Table V.
The effects of all school design variables on fifth grade ITBS scores

	Reading comprehension	Reading vocabulary	Language arts	Math	Social studies	Science
Movement and circulation	X		X	X		X
Day lighting		X				X
Views		X	X	X		

Table VI.
Where design significantly influences ITBS scores ($\alpha \leq 0.05$)

Source	Dependent variable	Tests of effects Type III sum of squares	Mean square	df	F	α
Corrected model	readcomp	4794.444[a]	4	1198.611	57.700	0.000
	readvoc	8011.772[b]	4	2002.943	39.063	0.000
	larts	3956.619[c]	4	989.155	20.148	0.000
	math	9197.439[d]	4	2299.360	52.330	0.000
	socstud	6521.326[e]	4	1630.332	39.963	0.000
	science	9649.792[f]	4	2412.448	38.285	0.000
Intercept	readcomp	7132.860	1	7132.860	343.371	0.000
	readvoc	10438.106	1	10438.106	203.570	0.000
	larts	9015.103	1	9015.103	183.627	0.000
	math	14321.354	1	14321.354	325.935	0.000
	socstud	12417.618	1	12417.618	304.387	0.000
	science	14392.975	1	14392.975	228.413	0.000
SES >	readcomp	3629.107	1	3629.107	174.703	0.000
	readvoc	7458.709	1	7458.709	145.464	0.000
	larts	3028.747	1	3028.747	61.692	0.000
	math	8407.096	1	8407.096	191.334	0.000
	socstud	6038.358	1	6038.358	148.015	0.000
	science	7954.001	1	7954.001	126.228	0.000
Movement and circulation	readcomp	241.236	1	241.236	11.613	0.000
	readvoc	49.004	1	49.004	0.956	0.332
	larts	422.923	1	422.923	8.614	0.005
	math	504.764	1	504.764	11.488	0.001
	socstud	65.056	1	65.056	1.595	0.211
	science	395.013	1	395.013	6.269	0.015
Day light	readcomp	58.332	1	58.332	2.808	0.099
	readvoc	264.620	1	264.620	5.161	0.026
	larts	64.913	1	64.913	1.322	0.254
	math	93.130	1	93.130	2.120	0.150
	socstud	26.704	1	26.704	0.655	0.421
	science	768.256	1	768.256	12.192	0.001
Views	readcomp	40.344	1	40.344	1.942	0.168
	readvoc	497.938	1	497.938	9.711	0.003
	larts	211.279	1	211.279	4.303	0.042
	math	764.967	1	764.967	17.410	0.000
	socstud	120.502	1	120.502	2.954	0.090
	science	53.540	1	53.540	0.850	0.360
Error	readcomp	1371.020	66	20.773		
	readvoc	3384.172	66	51.275		
	larts	3240.254	66	49.095		
	math	2899.997	66	43.939		
	socstud	2692.505	66	40.796		
	science	4158.856	66	63.013		
Total	readcomp	173612.000	71			
	readvoc	136808.000	71			
	larts	230189.000	71			
	math	221082.000	71			
	socstud	210246.000	71			
	science	229134.000	71			

(*continued*)

Table VII. The full regression with SES and school design variables

Table VII.

Source	Dependent variable	Type III sum of squares	Mean square	df	F	α
		Tests of effects				
Corrected total	readcomp	6165.465	70			
	readvoc	11395.944	70			
	larts	7196.873	70			
	math	12097.437	70			
	socstud	9213.831	70			
	science	13808.648	70			

Notes: $^{a}R^2 = 0.778$ – Reading comprehension; $^{b}R^2 = 0.703$ – Reading vocabulary; $^{c}R^2 = 0.550$ – Language arts; $^{d}R^2 = 0.760$ – Mathematics; $^{e}R^2 = 0.708$ – Social studies; $^{f}R^2 = 0.699$ – Science

Note

1. Three researchers collected school design data used in this study. Special thanks to Dr Kathleen Yarborough (2001) for her efficient work. Preceding Dr Yarborough's study, Ms Elizabeth Jago assisted me in collecting data, validating the original instruments, and assisting in pilot testing. Special thanks to the Georgia Board of Regents, the University of Georgia and the College of Education at UGA for funding research efforts of the School Design and Planning Laboratory and supporting all the graduate students that spent long hours working with me in the development and refinement of concepts found in this article, their dissertations, and other publications since 1997. The SDPL is indebted to the 19 Georgia school systems that allowed me, my research assistants, and graduate classes to tour their schools from 1997 to 2003.

References

Alexander, C. (1979), *The Timeless Way of Building*, Oxford University Press, New York, NY.

Alexander, C., Ishikawa, S. and Silverstein, M. (1977), *A Pattern Language*, Oxford University Press, New York, NY.

Andersen, S. (1999), "The relationship between school design variables and scores on the Iowa test of basic skills", unpublished doctoral dissertation, University of Georgia, Athens, GA.

Ayers, P.D. (1999), "Exploring the relationship between high school facilities and achievement of high school students in Georgia", unpublished doctoral dissertation, University of Georgia, Athens, GA.

Banghart, F.W. and Trull, A. Jr (1973), *Educational Planning*, The Macmillan Company, New York, NY.

Cicchetti, D.V. (1994), "Guidelines, criteria, and rules of thumb for evaluating normed and standardized assessment instruments in psychology", *Psychological Assessment*, Vol. 6 No. 4, pp. 284-90.

Duncanson, E. (2003), "Classroom space: right for adults but wrong for kids", *Educational Facility Planner*, Vol. 38 No. 1, pp. 24-8.

Ferguson, R.F. (2002), *What Doesn't Meet the Eye: Understanding and Addressing Racial Disparities in High-achieving Suburban Schools*, North Central Regional Educational Laboratory, Chicago, IL, available at: www.ncrel.org/gap/ferg/index.html (accessed March 24, 2008).

Hall, E. (1959), *The Silent Language*, Anchor Books, New York, NY.

Heschong Mahone Group (1999), *Day Lighting in Schools*, Heschong Mahone Group, Fair Oaks, CA.

Hughes, P.C. (1980), "The use of light and color in health", in Hastings, A.C. (Ed.), *Health for the Whole Person: The Complete Guide to Holistic Medicine*, Westview Press, Boulder, CO, pp. 71-83.

Iowa Test of Basic Skills (2008), College of Education, Iowa Testing Programs, The University of Iowa, Iowa City, Iowa, available at: www.education.uiowa.edu/itp/itbs/index.htm (accessed April 17, 2008).

Kuller, R. and Lindsten, C. (1992), "Health and behavior of children in classrooms with and without windows", *Journal of Environmental Psychology*, Vol. 12 No. 3, pp. 305-17.

Nair, P. and Fielding, R. (2005), *The Language of School Design: Design Patterns for 21st Century Schools*, DesignShare.com, Minneapolis, MN.

Ott, J. (1973), *Health and Light*, Simon and Schuster, New York, NY.

Sommer, R. (1969), *Personal Space*, Prentice-Hall, Englewood Cliffs, NJ.

Tanner, C.K. (2000), "The influence of school architecture on academic achievement", *Journal of Educational Administration*, Vol. 38 No. 4, pp. 309-30.

Tanner, C.K. (2006), "Effects of the school's physical environment on student achievement", *Educational Planning*, Vol. 15 No. 2, pp. 25-44.

Tanner, C.K. and Lackney, J.A. (2006), *Educational Facilities Planning: Leadership, Architecture, and Management*, Allyn and Bacon, Boston, MA.

Wohlwill, J.F. and van Vliet, W. (1985), *Habitats for Children: The Impacts of Density*, Lawrence Erlbaum Associates, Hillsdale, NJ.

Wurtman, R.J. (1975), "The effects of light on the human body", *Scientific American*, Vol. 233 No. 1, pp. 68-77.

Yarborough, K.A. (2001), "The relationship of school design to academic achievement of elementary school children", unpublished doctoral dissertation, University of Georgia, Athens, GA.

Appendix. Calculations to determine effects of school design variables on ITBS scores

The R^2 change in each of the six tables in this Appendix is interpreted as the effect. Therefore, the effect of all three sets of school design variables on Reading comprehension (Table AI), for example, is [(0.778-0.691) = 0.087], the R^2 change; ($\alpha = 0.000$). Table V reveals a summary of the following Tables AI-VI.

Descriptive statistics								
	Mean	*SD*	N					
Reading comprehension	48.563	9.384	71					
SES	53.993	18.473	71					
Movement and circulation	34.985	10.310	71					
Day lighting	12.647	3.312	71					
Views	30.211	8.153	71					
Model summary								
Model	R	R^2	*SE*	R^2 *Change*	F *Change*	*df1*	*df2*	α
SES	0.831[a]	0.691	5.255	0.691	154.260	1	69	0.000
Design	0.882[b]	0.778	4.557	0.087	8.576	3	66	0.000

Notes: [a]Predictors: (constant), SES; [b]predictors: (constant), SES, Movement and circulation, Day lighting, Views

Table AI. Effects on reading comprehension

Table AII.
Effects on reading vocabulary

Descriptive statistics	*Mean*	*SD*	N					
Reading vocabulary	42.028	12.759	71					
SES	53.993	18.473	71					
Movement and circulation	34.985	10.310	71					
Day lighting	12.647	3.312	71					
Views	30.211	8.153	71					
Model summary								
Model	R	R^2	*SE*	R^2 *Change*	F *Change*	*df1*	*df2*	α
SES	0.806[a]	0.650	7.602	0.650	128.186	1	69	0.000
Design	0.838[b]	0.703	7.160	0.053	3.924	3	66	0.012

Notes: [a]Predictors: (constant), SES; [b]predictors: (constant), SES, Movement and circulation, Day lighting, Views

Table AIII.
Effects on language arts

Descriptive statistics	*Mean*	*SD*	N					
Language arts	56.042	10.139	71					
SES	53.993	18.473	71					
Movement and circulation	34.985	10.310	71					
Day lighting	12.647	3.312	71					
Views	30.211	8.153	71					
Model summary								
Model	R	R^2	*SE*	R^2 *Change*	F *Change*	*df1*	*df2*	α
SES	0.674[a]	0.454	7.549	0.454	57.288	1	69	0.000
Design	0.741[b]	0.550	7.006	0.096	4.698	3	66	0.005

Notes: [a]Predictors: (constant), SES; [b]predictors: (constant), SES, Movement and circulation, Day lighting, Views

Table AIV.
Effects on mathematics

Descriptive statistics	*Mean*	*SD*	N					
Mathematics	54.253	13.146	71					
SES	53.993	18.473	71					
Movement and circulation	34.985	10.310	71					
Day lighting	12.647	3.312	71					
Views	30.211	8.153	71					
Model summary								
Model	R	R^2	*SE*	R^2 *Change*	F *Change*	*df1*	*df2*	α
SES	0.825[a]	0.681	7.483	0.681	147.013	1	69	0.000
Design	0.872[b]	0.760	6.628	0.080	7.315	3	66	0.000

Notes: [a]Predictors: (constant), SES; [b]predictors: (constant), SES, Movement and circulation, Day lighting, Views

Descriptive statistics								
	Mean	*SD*	N					
Social studies	53.211	11.472	71					
SES	53.993	18.473	71					
Movement and circulation	34.985	10.310	71					
Day lighting	12.647	3.312	71					
Views	30.211	8.153	71					
Model summary								
Model	*R*	R^2	SE	R^2 *Change*	*F* *Change*	*df1*	*df2*	α
SES	0.831[a]	0.691	6.422	0.691	154.408	1	69	0.000
Design	0.872[b]	0.708	6.387	0.017	1.252	3	66	0.298

Notes: [a]Predictors: (constant), SES; [b]predictors: (constant), SES, Movement and circulation, Day lighting, Views

Table AV. Effects on social studies

Descriptive statistics								
	Mean	*SD*	N					
Science	55.070	14.045	71					
SES	53.993	18.473	71					
Movement and circulation	34.985	10.310	71					
Day lighting	12.647	3.312	71					
Views	30.211	8.153	71					
Model summary								
Model	R	R^2	*SE*	R^2 Change	F Change	*df1*	*df2*	α
SES	0.794[a]	0.630	8.608	0.630	117.327	1	69	0.000
Design	0.836[b]	0.699	7.938	0.069	5.050	3	66	0.003

Notes: [a]Predictors: (constant), SES; [b]predictors: (constant), SES, Movement and Circulation, Day Lighting, Views

Table AVI. Effects on science scores

About the author

C. Kenneth Tanner is a professor at the University of Georgia, where he focuses on research, service, and teaching in the area of "How the physical environment influences student outcomes." He founded the School Design and Planning Laboratory in 1997 (www.coe.uga.edu/sdpl), which offers comprehensive guidance in school design and planning for public and independent schools. He, a member of the graduate faculty at the University of Georgia since 1982, has written over 100 articles for educational journals, presented numerous research papers, and authored four books on planning. He is on the Faculty of Engineering and the lead author of a 2006 publication entitled *Educational Facilities Planning; Leadership, Architecture, and Management* published by Allyn & Bacon. He works as a consultant to public and independent schools in the areas of student population forecasting, pre-planning activities, educational engineering, and planning and development of concept design for educational facilities. He is currently conducting research and developing materials to assess "green schools." C. Kenneth Tanner can be contacted at: cktanner@uga.edu