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Integrating community ergonomics with educational ergonomics – designing community systems to support classroom learning

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Abstract. This paper offers a conceptual framework, bolstered by empirical evidence, for two conclusions: (1) that variability in student learning is prominently influenced by ergonomic design features, not only of classrooms and school systems, but also of surrounding communities; and (2) a systems concept of learning environments therefore is required to support student learning, based on integrating educational with community ergonomics. Educational system design factors known to strongly influence student learning first are reviewed. One of the most prominent of these is the socioeconomic status of communities in which schools are housed. Independent lines of evidence then are introduced that may account for how and why community design affects learning. The paper closes with recommendations for persuading policymakers and educators that closer integration of school system operations and functions with those of the surrounding community, with a central goal of upgrading community design conditions, represents a highly promising opportunity for improving student learning performance. One major challenge is to heighten awareness that learning environments outside the classroom are as or more important as those inside, in terms of influencing not only test but broader educational and societal trajectories of children.

Keywords: educational ergonomics, community ergonomics, informal learn

1. Introduction

Remedies proposed to elevate academic performance of K-12 students in the U.S. and elsewhere are legion. This report introduces evidence for the conclusion that a common theme underlies almost all of these proposed solutions, namely their reliance on the design---the ergonomics/human factors (E/HF)---of educational system environments, features and operations.

Broadly speaking, educational ergonomics is concerned with designing learning environments to support student learning [1-8]. The scientific foundations of the field rest on a substantial body of empirical evidence, compiled over the past century, supporting the conclusion that the preponderance of variability observed in learning performance is attributable to the design---the ergonomics---of the learning environment [9-10].

Legg [3] and T.J. Smith [6] point out that the term 'learning environment' encompasses a broad array of microergonomic and macroergonomic design factors that have the potential to influence learning. Tables 1 and 2 group these design factors into two major categories, namely those that have reliably been shown to have a positive impact on K-12 student performance (Table 1), and those with equivocal or low impact on K-12 student performance (Table 2), based on available evidence.

2. Educational Ergonomic Design Factors with Positive Effects on Student Learning

Table 1, a compilation of design factors reliably shown to strongly influence student performance, lists the design factor category in the first column, the type of design factor in the second column, and a brief synopsis of the demonstrated impact of the specified design factor on student performance in the last column (with references to supporting evidence). A total of 8 different factors, divided into 6 categories, are specified in the table---evidence for their positive impacts on student performance is summarized below.

Classroom and School Building Environmental Design. Evidence supporting the positive influence of good environmental design of classrooms and schools on student performance may be summarized as follows.

- The research of Caldwell [11] supports the estimate that poor classroom design and maintenance can lead to decrements of 10–25% in student performance.
- Schneider [12] and Horrell [13] summarize evidence that the academic performance of K-12 students is adversely affected by poor control of classroom environmental indoor air, room ventilation, temperature, humidity, thermal comfort, lighting and acoustic quality.
- Classroom furniture, properly designed for children, improves on-task behavior, promotes better sitting and standing postures, reduces back pain and other musculoskeletal complaints, increases trunk muscle strength, and improves overall academic marks [13-15].
- Introduction of appropriate colors, full-spectrum lighting, plants, and background music in school classrooms promotes a more relaxed, calming and attractive learning environment [16], but their possible effects on academic achievement are as yet unproven.
- The foregoing findings have prompted the emergence of various occupancy quality guidelines and standards pertaining to ergonomics for children [17-18].

Longer Exposure to Learning. A compelling body of evidence, compiled from charter schools that adhere to extended schedules advocated by programs such as the Knowledge is Power or Harlem Children's Zone, indicates that compared with children in typical public schools, those who are required to spend a greater number of hours per year in the classroom achieve notable gains in learning performance [19-22]. Experience with extended school schedule designs has been shown to overcome gaps in learning performance between black versus white, and economically more versus less disadvantaged, students.

Cooperative Learning. As conclusively shown by the Johnson brothers at the University of Minnesota, class designs built around cooperative learning groups or teams reliably yield superior learning outcomes, compared with classes based on individualized learning or competitive learning group designs [23-25].

Early Childhood Education. With the possible exception of the socioeconomic status of school communities (below), no other design factor has been shown to exert a greater influence on school performance, and lifelong success generally, than early childhood education. Persuasive evidence for this conclusion comprises:

- the High/Scope Perry preschool project [26], in which, relative to preschoolers not so enrolled, kids enrolled in a half-day preschool program, displayed positive effects related to scholastic success, social responsibility and socioeconomic success;
- the Chicago Child Centers study [27], prompting the study's author to note that, 'no other social program has the evidence to show this level of savings to society;'
- studies of the economic benefits of early childhood education [27,28]---the latter author cites an ROI of 7 to 16 percent a year from early childhood learning programs for at-risk kids;
- an entire special section of the August 19, 2011, issue of *Science* (with a total of 10 reports), documenting the benefits of investing early in education [29].

Student Health and Wellbeing. Multiple observations point to two other design factors that appear to be related to student performance in the classroom, namely: (1) a child's physical fitness level generally as well as physical activity programs at school; and (2) adequacy of a child's nutrition generally, plus supplemental nutritional programs at school [30-34].

Student Emotional Well-Being. Exposure to environmental stressors, such as frequent transfers between schools [35], parental divorce [36], or adverse childhood experiences [37], adversely impacts student academic performance.

Teaching Quality. A 2004 report asserts that, 'A growing body of research shows that the quality of the teacher in the classroom is the most important schooling factor predicting student outcomes' [38]. A more recent article notes that, 'Budget, curriculum, class size---none has a greater effect on a student than his or her teacher' [39].

There is broad support for these claims, such as: (1) the U.S. federal No Child Left Behind and Race to the Top initiatives both emphasize teacher accountability as the key to improving schools; (2)

the basic assumption of the Bill and Melinda Gates Foundation [40] is that provision of high quality teaching will ensure student success; (3) the agenda of the National Commission on Teaching and America's Future (NCTAF) [41,42] rests on what this entity considers the single most important strategy for achieving America's educational goals, namely recruiting, preparing and supporting excellent teachers; and (4) the international supremacy of Finnish schools is attributed to how they prepare and manage their teaching corps [43,44].

Yet the strong claim that 'teachers matter most' is muted by evidence documented in the present report. That is, among the design factors identified in Table 1 with a positive impact on student performance, only use of cooperative learning strategies is under direct control of the teacher. Holding teachers accountable for mediating the impact on student learning of a series of design factors that they cannot control may be deemed at best ineffective, and more pointedly a recipe for failure on the part of teachers and students alike. This consideration supports a balanced conclusion that teaching quality represents a necessary, but not sufficient, contributor to student achievement.

3. Educational Ergonomic Design Factors with Equivocal Effects on Student Learning

The design factors addressed in the preceding section, reliably shown to positively impact student learning, do not include a number of factors traditionally favored by the educational establishment as key determinants of student learning. Table 2 lists a series of such factors shown to have more equivocal effects on learning, namely: (1) amount of homework; (2) informal learning; (3) classroom technology; (4) online learning environments; (5) class size; (6) school choice; (7) school funding level; (8) school size; (9) school start time; (10) teacher pay level; and (11) teacher training level. Objective evidence supports the conclusion that the actual learning effects of these factors are either marginal or negligible---Table 2 provides references supporting this conclusion.

4. Community Socioeconomic Status

This brings us to what I submit represents a highly compelling example of an intimate link between design and student performance, namely the relationship between the socioeconomic status of a community and the performance of students attending schools in that community (Table 1). As used here, the term 'socioeconomic status' refers to the average levels of both economic well-being and social cohesion and interaction in a given community. This essentially represents a profile of community ecology, characterized by such indicators as life expectancy and other measures of community health, literacy and educational achievement, crime levels, and levels of employment and welfare dependency, along with less-tangible factors such as personal dignity and safety, and the extent of participation in civil society.

I use the term *community ergonomics* to refer both to the collective set of system design factors that define the socioeconomics of a community, as well as to the study of these factors [65].

Evidence implicating the critical influence of community design on educational performance has emerged with results from standardized tests of mathematical ability and reading comprehension administered to 8th graders (age 13 years) in public school districts in the State of Minnesota. The findings show a high correlation between test performance and percentage of low income students in different districts. Representative results for 49 Minnesota urban and suburban public school districts in the Minnesota Twin Cities (i.e. Minneapolis and St. Paul) metropolitan area, for the years 1996, 2002, 2006 and 2009, are summarized in Figure 1.

The choice of this particular set of data for the analysis is based on the following considerations: (1) the state of Minnesota started administering statewide basic skills tests in math and reading in 1996, and then only to 8^{th} graders---up to the present, 8^{th} grade test results thus span the longest period of time for which district-by-district comparison of student performance is possible; (2) the Twin Cities metropolitan area features school districts with a broad range of income levels for 8^{th} grade student families, with high percentages of low income families for strongly urban districts such as Minneapolis (64% in 2009) and St. Paul (77% in 2009), versus low percentages for suburban districts such as Edina (6.5% in 2009).

Figure 1 plots the linear regressions of test scores for 8th graders in these 49 districts (average of mathematics and reading scores combined), as a function of the percentage of low income students (the percentage of 8^{th} grade students in different districts receiving free or low-price lunches), for the years 1996 (diamond symbols), 2002 (square symbols), 2006 (triangle symbols) and 2009 (star symbols), based on publicly reported data [66-70]. Each symbol in the figure represents results for one district. For districts with 8th grades in more than one school, both test score results and low income percentages are averaged across all of the 8th grades in the district. To enable comparison of results for different years (and for revised tests in 2006 and 2009), the average test scores by district are normalized for each year, with the highest average score assigned a value of 100. Note that the regression lines for the 2006 and 2009 results are virtually indistinguishable.

Results in Figure 1 indicate that variance in average test scores across districts progressively decreases from 1996 to 2009 (as shown by the progressively lower regression line slopes for these years). Nevertheless, for each of the four years, the regression of averaged math and reading scores by district on percentage of low income students is highly significant, with R-squared values of 0.73, 0.77, 0.65 and 0.75 respectively for 1996, 2002, 2006 and 2009.

These values mean that from about two-thirds (for 2002) to about three-fourths (for 1996, 2006 and 2009) of the variance in average test scores is accounted for by regression on percentage of low income students.

There are evident limitations to the results in Figure 1. One obvious point is that correlation does not prove causation. Nevertheless, that a robust relationship between test scores of 8th graders and the socioeconomic status of their school districts persists across a span of 14 years strongly suggests that the school performance of these students, and the socioeconomic conditions in the communities in which they reside, are inextricably intertwined in some fashion. Of equal importance is the point that these are data from one grade for a select number of school districts in only one metropolitan area of one U.S. state. It is by no means certain that similar patterns would be observed elsewhere. Also, the data pertain to test results for only two subjects, namely math and reading. Finally, implicit in this analysis for purposes of this paper is the assumption that test performance is equated with learning proficiency.

5. Integrating Educational Ergonomics and Community Ergonomics

Despite the limitations cited above, let us take the data in Figure 1 at face value and assume that they would be replicated in other areas of the U.S. (and possibly in other countries as well) that encompass school districts whose communities embody a reasonable distribution of socioeconomic wellbeing. In support of this assumption, a recent report [71] cites large gaps in high school graduation rates between U.S. cities and suburbs---the average urban rate in the nation's largest cities was 53 percent, compared with 71 percent in the suburbs.

Based on the foregoing assumption, the findings in Figure 1 support a number of compelling conclusions. First, across a 14-year period, the strong correlation between average 8th grade math/reading test scores by school district, and the percentage of low income 8th grade students in different districts, remains highly consistent and reproducible. Second, the percentage of low income 8th grade students in a given school district arguably represents a socioeconomic design factor, varying in a manner that is largely independent of biological factors such as gender and IQ. This conclusion is bolstered by findings from a recent study showing that, in healthy students, there is little difference in IQ and mathematics test scores between socioeconomically advantaged and disadvantaged students of different ages [72].

Third, it is rare in educational psychology to be able to account for two-thirds to three-fourths of the variance in a dependent variable of learning performance with a single independent variable. That such a high and reproducible degree of dependence of test performance on percentages of low-income students is in fact observed implies that remedial strategies unrelated to underlying prevailing socioeconomic conditions in a school district will at best address only about one-fourth to one-third of the variance in math and reading test scores for Twin Cities metropolitan area 8th graders.

These considerations lead to the key conclusion of this paper regarding the interaction of learning performance and community design, which is that the aims and objectives of educational ergonomics and community ergonomics are intimately coupled. The primary aim of community ergonomics is to improve socioeconomic conditions in communities through application of principles and methods of ergonomic systems engineering directed at improving community socioeconomic design characteristics [65,73-75]. Community ergonomic interventions that yield improved quality in community socioeconomic conditions therefore also should yield improved learning performance in community schools. This consideration has prompted T.J. Smith [6] to suggest that school districts should adopt the principle that, 'the boundaries of a school are the boundaries of its community.'

What specific socioeconomic design factors in a community tend to either nurture, or undermine, learning performance of students who attend schools in that community? M.J. Smith et al. [65] point out that high parental involvement in schools and formation of school–community alliances are linked to good educational performance, whereas low socioeconomic and educational status of parents and poor nutrition of children are linked to poor performance. Evidence pointing to an inverse relationship between nutritional sufficiency and student academic performance is aligned with the inverse relationship between Twin City school district poverty indices and 8th grade test score performance.

The link between community socioeconomic status and student achievement may also be related to the inverse relationship observed between adverse childhood experiences (more prominent in socioeconomically disadvantaged relative to socioeconomically advantaged communities) and student academic performance in school [37].

Other observers point to three major sets of factors that account for the link between community design and learning outcomes, namely family interaction and support, development and refinement of socioemotional skills, and nurturing of personal qualities of self-confidence, dedication to hard work, and trustworthiness. Brooks [76] frames these points in terms of the significance of introducing and improving elements of cultural, social, moral, cognitive self-awareness, and aspirational capital in children, in order to promote achievement both inside and outside of school.

Let me conclude this analysis by introducing what I believe represents the most critical community design factor in terms of the link between community socioeconomic status and learning, a factor that pervasively influences all of the other factors cited above. I refer to the relative quality and status of work activity---encompassing such indicators as levels of job security, un- and under-employment, family income and debt, and job satisfaction and fulfillment, as well as work schedule and commuting patterns---in different communities. Indeed, Peck [77] offers a compelling argument that the great recession that started in 2008 has ushered in an era of high joblessness that threatens to change the life course and character of a generation of young adults, leave an indelible imprint on blue-collar communities, plunge inner cities into depths of despair not seen for decades, and warp our politics, our culture and the character of our society of years to come. Inevitably, as suggested by Figure 1, the educational and societal fates of millions of children likely will also be adversely affected.

6. Possible Solutions and Recommendations

How might the designs of community systems be improved to benefit the learning performance of children, a goal embodied in the integrative hypothesis set forth in this paper? One major challenge is to heighten awareness of policymakers and educators that informal learning environments outside the classroom are as or more important as those inside, in terms of influencing not only test but broader educational and societal trajectories of children [51]. Given that the typical U.S. child averages only 6.5 hours in class and one hour of homework per weekday [21], this means that a child spends about two-thirds of waking hours interacting with learning environments, largely defined by community design factors, outside the classroom.

There are some nascent, yet promising, signs that such awareness might be emerging. For example, the city of St. Paul, Minnesota has announced an initiative to integrate city, county and school district efforts to upgrade infrastructure and recreation programs, social services, and academic, teacher training and parent outreach programs in communities surrounding two elementary schools (servicing children ages 5-11) in the city (Havens & Patterson, 2010). The theme of this effort is, ‘add community involvement, take away poverty, and it will equal higher student achievement.’

A challenge of equal magnitude is to promulgate the concept among policymakers and the educational community that improving the educational performance of school systems represents both an educational and a community *design* challenge. This is where the field of ergonomics/human factors (E/HF) can and should play a role. I am aware of no systematic E/HF research on the interaction of community design and human performance. The field has had marked success over the past decade in highlighting the importance of E/HF design in the health care field, and comparable (but less advanced) efforts are now underway in the field of education. Community design should be our next systems target---establishing an IEA community ergonomics technical group would be a good start.

7. References

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Table 1. Design factors reliably shown to have a positive impact on K-12 student performance, based on available evidence.

Category	Design Factor	Impact on Student Performance
Classroom and School Building Design Factors	Environmental Design of Classroom and Building Facilities	Student academic performance influenced by level of classroom and school building design quality [11-18]
Educational System Design Factors	Longer Exposure to Learning	Strongly positive [19-22]
Learning Strategy Design Factors	Cooperative Learning	Strongly positive [23-25]
	Early Childhood Education	Strongly positive [26-29]
	Teaching Quality	Necessary, but not sufficient [38-44]
Design Factors Influencing Student Physical Health and Wellbeing	Good Physical Fitness Levels and Participation in Physical Activity, plus Nutritional Adequacy	Largely positive [30-34]
Design Factors Influencing Student Emotional Wellbeing	Student Exposure to Stressors	Strongly positive [35-37]
Community System Design Factors	Community Socioeconomic Status and School-Community Integration	Strongly positive [6,7]

Table 2. Design factors with equivocal or low impact on K-12 student performance, based on available evidence.

Design Factor	Nature of Impact, Based on References Cited
Amount of Homework	Varied results [45-47]
Classroom Technology	Equivocal effects of computer use [48,49,50]
Informal Learning	Promising but limited and not definitive positive results [51]
Online Learning Environments	No systematic analysis yet available [52]
Smaller Class Size	Positive for lower but not for higher grades [53,54]
School Choice	Varied effects, depending on country [55]
School Funding	No relationship [56-58]
School Size	Varied results [59-60]
School Start Times	Non-academic benefits, but academic impact unproved [61-62]
Teacher Pay Level	No relationship [63]
Teacher Training Level	No relationship [38,64]

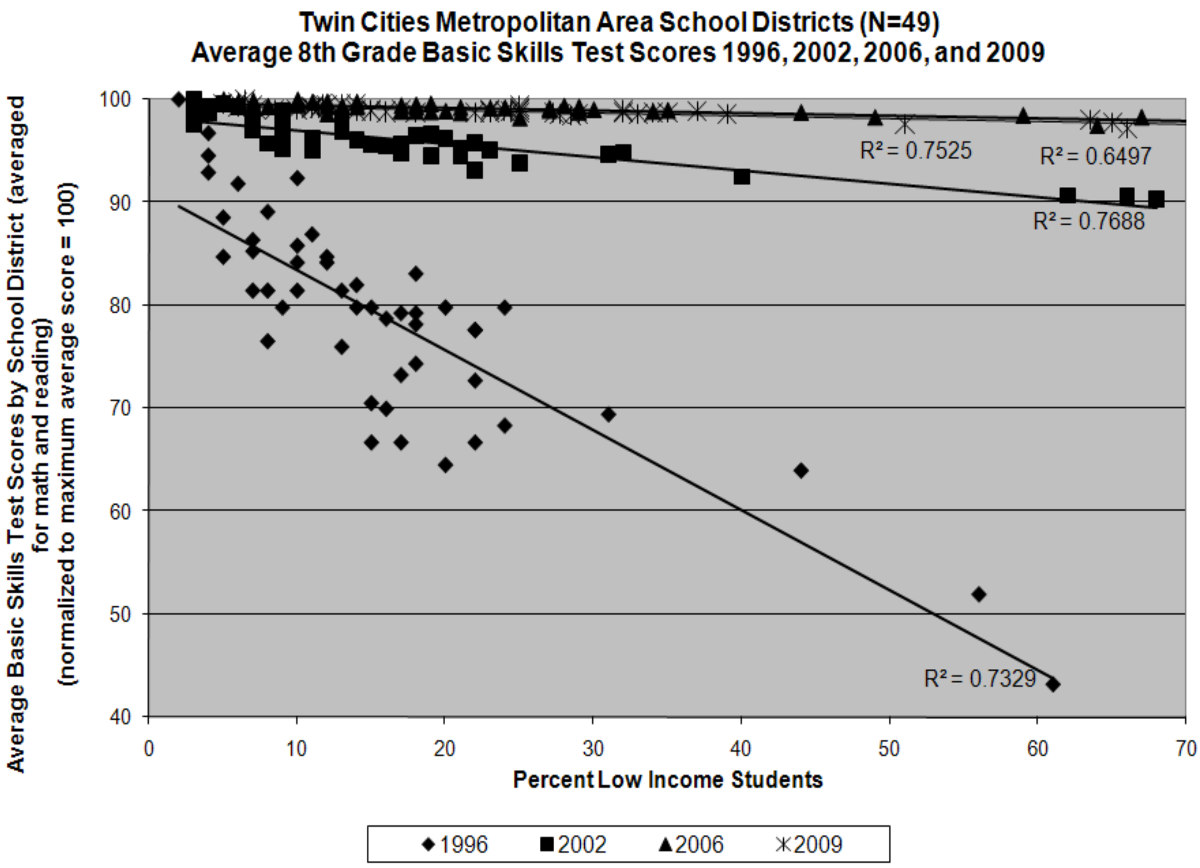

Figure 1. Basic skills test scores, averaged for both math and reading, for Minnesota 8th graders by school district for the years 1996, 2002, 2006 and 2009, in relation to the percentage of low income students, for 49 different districts in the Minneapolis/St. Paul metropolitan area, based on publically reported data [66-70].