DESIGN
Principles & Practices:
An International Journal

Volume 3, Number 2

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DESIGN PRINCIPLES AND PRACTICES: AN INTERNATIONAL JOURNAL
http://www.Design-Journal.com

First published in 2009 in Melbourne, Australia by Common Ground Publishing Pty Ltd
www.CommonGroundPublishing.com.

ISSN: 1833-1874
Publisher Site: http://www.Design-Journal.com

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Typeset in Common Ground Markup Language using CGCreator multichannel typesetting system
http://www.commongroundpublishing.com/software/

Complexity and Design: How School Architecture Influences Learning

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Abstract: Problems with education are not only about curriculum methods, assessment, or teacher competency. Some of our pedagogical challenges have to do with the ways in which we design school buildings and grounds. This theoretical paper explores how school architecture can be expected to shape the nature of learning by drawing on existing research and models of design and human behaviour. Empirical studies over the last seven or eight decades have clearly established that attributes such as light, temperature, noise, and air quality have an impact on teaching and learning. Where these environmental attributes are inadequate, there are negative effects on attention, behaviour, and academic achievement. However, the research on how teachers and students might benefit from architecturally thoughtful and supportive environments—good design—is less clear. In this paper, arguments are made for paying closer attention to the more subtle elements of design, such as those bearing on ease of movement, intimate and community gathering places, and positive outdoor space. These arguments are supported by examples of Reggio Emilia and Waldorf schools, where architecture is recognized as a powerful and subtle teacher. The paper uses complexity science theory—which seeks to explain how self-organizing systems function—as the central theoretical framework to characterize learning and elements of design in schools and school grounds. The paper provides compelling arguments of how architectural patterns and design, in the context of place-based learning, can positively influence behaviours and experiences.

Keywords: Complexity Science

PROBLEMS WITH EDUCATION are not only about curriculum methods, assessment, teacher education, or teacher competency. Some of our educational challenges have to do with the ways in which we design school buildings themselves. This paper explores how school architecture shapes the nature of experiences of students and teachers. By using both empirical findings and theoretical models it is argued that thoughtfully designed schools can enhance learning in a host of important ways.

The paper is divided into five major sections. The first section outlines empirical research on the effects of school architecture on learning and well being, focusing on the use of natural light as an example of an important architectural design consideration. The second section calls for an examination of how the built and natural environments associated with schools can lead to an enhanced sense of place for students. Third, complexity science theory is presented as a way of thinking about the interaction between learning and architectural design. Fourth, patterns of architectural design are considered in light of the complexity theory framework. Finally, examples of schools that have been successfully designed or renovated in ways that resonate with complexity theory are discussed.

Design Principles and Practices: An International Journal
Volume 3, Number 2, 2009, http://www.Design-Journal.com, ISSN 1833-1874

Empirical Research on the Effects of School Architecture

School architecture affects the social interactions, physical growth, emotional development, and intellectual attainments of its students. School architecture also embodies cultural messages: many scholars have argued that contemporary schools have been built for young people to be trained for the bureaucracy of work (Wente, 2004). Thus, we find many schools that are box-like, transmitting the message that the best education is efficient, linear, and organized. Buildings can also be fashioned to reinforce, for example, the importance of a classical education. In 1847, British architect Henry Kendall urged school builders to use a gothic style for just that purpose (Dudek, 2002).

More new buildings will be constructed in the first half of the 21st century than have been built in all of recorded human history (Orr, 1999). Many of those buildings will be schools; never has there been a more opportune time to think deeply about school design. Annual school construction budgets in the United States hover around $20 billion, even in times of economic hardship (Abramson, 2007). But are the schools we are now building transmitting the messages we wish for them to transmit? Are we creating the best environments for learning?

It seems self-evident that the kind of spaces children and their teachers inhabit will affect how and what they learn. There have been a series of studies examining the importance of well-designed facilities on academic performance for students (e.g., Berner, 1992; Peters, 2003). Research demonstrates that students are more likely to achieve high levels of academic performance if the schools they attend are well maintained, meet safety standards, and are kept clean. Students in schools with leaking roofs, broken windows, missing toilet stalls, and dark classrooms don’t fare so well (Kolleeny, 2003; Lezotte & Passalacqua, 1978; Tanner & Langford, 2003; Rittelmeyer, 1992). An architectural feature that is directly related to academic performance, and which has been studied extensively for decades, is that of the presence of natural light. Some of these studies are now examined.

Natural Light

For nearly a hundred years, engineers, architects, psychologists, and educators have examined the associations between lighting and learning, with health and physiology, and with behavior, concluding that natural light has a positive effect not only on learning, but on the physical well-being of students in schools (Dudek, 2000; Hathaway, 1995; Rice, 1953; Rittner-Heir, 2002; Romney, 1975; Sherman, 2001). Some of the aforementioned studies on lighting have been highly controlled and longitudinal in nature, such as the research of Matthew Luckiesh and Frank Moss (1940), carried out in Joplin, Missouri. In this study, students’ achievement scores were compared over a three-year period. Students were assigned to one of four north-facing classrooms: two experimental classrooms—with better lighting—and two control classrooms with inferior light. Students were matched at the beginning of the study in terms of socio-economic status and school achievement. At the end of the three-year period, the gains in achievement for the students in the experimental rooms with the better lighting, which included a combination of artificial and natural light, were significantly higher than those for the students in the two poorly lit control rooms.

A study carried out some thirty years later used a similar experimental design, this time reporting on the experiences of sixth grade students in Albuquerque, New Mexico (Romney, 1975). In this case, students in windowless classrooms were compared with students in classrooms with windows. The students who took part in the study were matched in terms of socio-economic status, and in terms of all other architectural aspects of the two classrooms, right down to the vinyl-asbestos flooring, ventilation, and acoustic ceiling tiles. Students in the windowless environments were more likely to be bored and to display aggressive behaviour, indicating that the presence of daylight positively affects behavioural outcomes.

More recent research on the effects of lighting has taken the approach of comparing test scores across school districts. For example, the achievement of 21,000 students in three school districts in California, Washington, and Colorado was analyzed after controlling for family income and education levels. The researchers found that where natural light was used, students academically outperformed their peers (Plympton, Conway, & Epstein, 2000). A similar Canadian study demonstrated how students in full-spectrum lit classrooms were less likely to be absent from school than their peers (Hathaway, 1995).

There are also physiological effects associated with lighting. A comprehensive study demonstrating the detrimental effects of poor lighting was undertaken in Sweden, where it was shown that students who were in classrooms that lacked both natural and artificial daylight demonstrated a marked delay in the annual rise of cortisol, a hormone associated with stress reduction. This delay caused the authors to conclude that environments lacking adequate illumination resulted in severe disturbances in the chronobiological system regulation of the production of hormones (Küller & Lindsten, 1992). The authors also concluded that children with the lowest cortisol levels in December were more likely to experience illness. In addition, researchers measured diurnal ranges of cortisol and found that students with high levels of morning cortisol were inclined to be more sociable than their peers, while students with overall moderate values of cortisol were more able to concentrate on their individual schoolwork. The authors concluded that working and living in classrooms without daylight upset a basic chronobiological rhythm, and in turn, this change in rhythm influenced students' abilities to concentrate and socialize, and had impact on overall health. Members of the Swedish government and the school board were so taken with the results of this study that they provided funds to install windows for the two windowless classrooms used in the study.

Deeper Effects of School Design: Place-based Education

The emphasis of research of the type just described tends to be limited to the effects of architectural space on academic performance, health and behaviour. There is less research on what are issues of equal importance: how school architecture both influences what is taught, and how it helps (or doesn't help) people develop affection and stewardship for the natural world.

Students who are fortunate enough to be schooled in places where the natural environment is one of their teachers may also learn to know and love the land around them and come to steward the earth in ecologically meaningful ways. From this understanding of how students learn about the natural environment comes a burgeoning movement called place-based education. With increasing concerns about disruptions to the environment caused by fundamentally unsustainable practices, scholars in many fields have turned to an examination of indigenous ecologically sensitive traditions. These fields include environmental studies (Ellens, Parkes, & Bicker, 2000), environmental philosophy and eco-justice (Bowers, 2001; Glasson, Frykholm, Mhango, & Phiri, 2006), ecofeminism (Gradle, 2007), and artistic and aesthetic practices (Broudy, 1972/1994; Leuthold, 1998; Matsunobu, 2007). Architects and scholars studying the built environment have also engaged in this discussion. For example, American environmentalist and architectural critic David Orr (1992) claims that education for sustainability must connect knowledge of subject disciplines with knowledge of place and the hands and heart.

Orr (1999) makes the sobering observation that place has no particular standing in contemporary education. He claims it is easy to overlook the importance of place in schooling because schools are immediate and mundane. In keeping with Orr's conclusion, architect William Bradley (1998) found most school construction is set in motion to renovate or replace unsafe or overcrowded facilities. Further, innovative designs often meet with opposition because there is a perception that such designs are necessarily more costly. Perhaps most significant of all, Bradley found that the general public simply does not think about how natural and built environments affect education.

Orr (1999) claims that many people in consumer-driven countries are "deplaced." Architectural expressions of deplacement include box stores, multi-lane freeways, steel and glass office towers—and schools. None of these architectural expressions encourage a sense of connection or responsibility. But surely schools should foster a sense of place. Over a century ago, Dewey claimed that schools should be thought of as embryonic communities, with activities in schools chosen to reflect the undertakings of society as a whole (Dewey, 1956/1900). For both Orr and Dewey, place contains the physical environment and the relationships and work of the community. Indeed, many prominent educational philosophers of the 20th century considered manual skills as essential elements of education (e.g., Montessori, 1967; Noddings, 2007; Whitehead, 1929). A number of contemporary curriculum developers and researchers focus on how school environments can support learning through practical activity and play (e.g., Adams, 1991; Burriss & Boyd, 2005; Moore & Wong, 1997). Attention to place is a central aspect of complexity science theory, as will be evident in the discussion that follows.

Complexity Science Theory

Complexity theory first arose as a defined field of study in the latter half of the 20th century when various branches of science and mathematics evolved into new areas (Capra, 1996; Johnson, 2001). Complexity science involves the study of adaptive and self-organizing systems such as ant colonies and pigeon flocks. Because complexity theory seeks to explain how a system functions when there are multiple members involved in some form of self-organization, scholars have applied this orientation to describe learning settings, including the classroom collective and other learning clusters that form in the school community (Davis & Sumara, 2006). Further, complexity theory implies that biological and cultural systems shape learning (Tomasello, 2000). Biological bases of knowing are often either ignored or suppressed in most Western discussions of knowledge and teaching. Complexity theory offers a way of bringing those influences back into the discourses of teaching and learning (Davis & Sumara, 2006). And, by its very nature, architecture embodies both biological and cultural systems. Complexity science thus provides a language for describing the interaction between learning and the architectural features of schools.

Key Conditions for Complexity

There is wide agreement about the key conditions that allow complex systems to arise. These conditions include redundancy, diversity, neighbour interactions, and enabling constraints (Johnson, 2001). Redundancy—that is, common elements—makes the system robust, and such redundancy is present in most classrooms simply because most children are of a similar age. But diversity is also needed to enable a system to respond in flexible ways to new situations. Redundancy and diversity work together through neighbour interactions where diverse ideas come into contact, and contradict, harmonize, or amplify one another. This exchange of ideas through neighbour interactions is often referred to as the bumping up of ideas. The collective also requires enabling constraints, that is, a shared structure allowing for emergence of unexpected phenomena and learning.

From a design perspective, freedom of movement is one feature that facilitates neighbour interactions, so it should come as no surprise to find a positive relationship between freedom of movement and academic achievement (e.g., Tanner, 2000). Sara Snyder Crumpacker, an American organizational consultant, says that, "Schools should be planned so that users 'bump into' different choices on a daily basis" (Crumpacker, 1995, p. 35). She suggests buildings should include informal areas to congregate that are "as comfortable as our own family rooms" (p. 40). In order to facilitate the bumping up of ideas—the informal learning that happens as a result of unplanned interactions in a complex system—architectural spaces like nooks, wings, or alcoves are needed, like those commonly found in Reggio Emilia and Steiner schools, discussed in a subsequent portion of this paper.

The bumping up of ideas is also fostered through access to technology embedded throughout a school building (Nair, 2002). Nair suggests that deep engagement in learning is supported by the presence of presentation spaces, getaway spaces and niches, and easy access to technology. With ubiquitous access to wireless laptops, students come into contact not only with those people who share the same learning space, but also, with other students who share similar interests in other parts of the world (Nair, 2002). This notion of easy access to technology can be viewed as a contemporary version of one of the features of Dewey's Utopian schools where there would be books everywhere (Dewey, 1989/1933). Teacher workrooms for research, collaborative work, and meetings with students also facilitate neighbour interactions and the bumping up of ideas (Bullock & Foster-Harrison, 1997; Nair, 2002).

A Pattern Language: Alexander and Tanner

Despite the many new theories of learning spawned over the past century, which include not only complexity theory, but also, for example, Dewey's progressivist notions (1956/1900), school architecture has not kept pace. School buildings continue to embody a transmission model, reinforced through high-stakes testing and related policy and funding decisions. Many people have called the transmission model, and the schools that come with it, into question (e.g., Day, 2001; Papert, 1993). An architectural pattern language provides another framework for talking about the architectural features of schools, and for relating these features to complexity theory and learning.

In the late 1970s, architect Christopher Alexander and his colleagues published what is now a classic text on design (Alexander, Ishikawa, & Silverstein, 1977). Alexander's aim was to provide a sourcebook of patterns for the built environment by taking into account human behaviours and perceptions. By "pattern," Alexander referred to a recurring problem in the built environment (e.g., large parking lots) for which he offered a core solution and related it to other patterns in the environment (e.g., how *small parking lots* can be created in urban settings in conjunction with *green streets* and *work communities*). One of the key premises of the approach is that patterns relate to one another. Fundamentally, Alexander's approach offers an architectural language capable of describing complex systems. For example, the patterns of *activity pockets* and *alcoves* encourage neighbour interactions, while the pattern *family of entrances* creates redundancy or common architectural elements.

In order to determine the effects of design on student achievement, American school designer Kenneth Tanner developed a school design scale based on Alexander's patterns (Tanner, 2000). His scale included several of Alexander's patterns such as *green areas*, *play areas*, *flex zones*, *small group areas*, *outdoor rooms*, *pathways*, and *natural light*. After taking into account various socio-economic variables in the 44 elementary schools that he examined, Tanner concluded some of the best predictors of achievement in language and mathematics were *pathways* (clearly defined areas for freedom of movement), and *positive outdoor spaces*. Yarbrough (2001) and Andersen (1999) applied modified versions of Tanner's design scale to other schools, and once again, architectural patterns that would support the emergence of complexity were identified as most significant.

Examples of School Designs Where Complexity and Pattern are Paramount

In this section of the paper, complexity and pattern examined in three contexts: (a) Reggio Emilia and Waldorf schools, where the underlying philosophy and design pay direct attention to architectural concerns, (b) a school remodeling where improvements in design positively affected outcomes, and (c) a purpose-built school environment where place-based education and complexity science were key design considerations.

Reggio Emilia and Waldorf Schools

Reports on school effectiveness in England and the United States rarely mention the quality of the built environment (Dudek, 2002). In Europe, however, the influence of architecture on education is widely acknowledged by architects, educators, and the public (Dudek, 2000). Throughout Europe, and especially in Germany, Italy, and Spain, particularly high priority is placed on architecture for pre-school and early childhood education. Much can be learned from these early childhood environments in the design of schools for older students as well.

The founders of both Reggio Emilia and Waldorf schools recognized that architecture is both a powerful and subtle teacher and these architectural notions are explicitly woven into the curriculum and pedagogy of Waldorf schools. Some of Alexander's patterns that support complexity—such as *living views* and *paths with goals*—are important features of Reggio and Waldorf schools. The Reggio Emilia and Waldorf approaches also share some fundamental features and histories. Founders of each approach articulated an explicit vision and corresponding curriculum, the core of which is reflected in contemporary schools. Both approaches were developed in Europe in direct response to violence, with the goal of cultivating citizens motivated by peace and civility. Teachers involved with these approaches recognize children as intelligent, creative, and complex beings. Also, teachers carefully prepare aesthetically pleasing environments to support student growth (Edwards, 2002). In fact, Rudolf Steiner, founder of Waldorf schools, claimed most of society's problems are rooted in its architecture (Raab, 1980).

The Reggio Emilia approach—which refers both to the pedagogy and the place in Italy where it was first developed—was the inspiration of Louis Malaguzzi. After visiting a village near Reggio, heavily bombed during World War II, Malaguzzi sought out other educators and parents who were united in their ambition to create schools for a democratic society (New, 2000). A number of municipal Reggio Emilia schools had already been established even before the passing of a 1968 national law to ensure pre-school education for working families with young children. For the next two decades, Reggio educators concentrated on two complementary efforts: building more schools, and joining regional and national discussions about the aims and methods of education. The *Hundred Languages* exhibit was one of the results of these discussions, where documentation was painstakingly gathered to promote understanding of children's development (Gardner, 1999). This traveling exhibit features children's artifacts, photographs of children working in Reggio environments ("ateliers" filled with plants and natural light, which feel more like studios than classrooms), transcriptions of children's conversations, and teachers' reflections. One of the key features includes the notion of the role of the environment as teacher. Also featured are the primacy of the home-school relationship and children's multiple symbolic languages (Gardner, 1999).

In 1919, with the devastation of World War I still at the forefront of people's consciousness, factory owner Emil Mott invited Steiner to create a school for the children of the employees of the Waldorf-Astoria cigarette factory, in Stuttgart, Germany (Oppenheimer, 1999). Mott hoped for a form of schooling that would enable its graduates to create a just and peaceful society. Steiner, too, felt there was a need for a social order that included more compassionate ways of resolving conflict (Oppenheimer, 1999)—goals that feel remarkably contemporary in the context of today's global situation. In many ways, the school was revolutionary: it was coeducational, open to children from any background and ability level, it spanned preschool to high school, and it was independent of external control (Edwards, 2002). For Steiner, an architect himself, every aspect of the school—the furniture, colours, lighting, natural objects—had architectural and pedagogical significance (Henry, 1993; Oberman, 1997). Students at Waldorf schools develop a sense of place through attention to natural patterns and rhythms. Dudek (2000) suggests Waldorf schools provide "the clearest manifestation of a pedagogic and architectural convergence during the past 40 years" (p. 62).

While it is beyond the scope of the present paper to examine individual examples of Reggio Emilia and Waldorf schools, it is clear that there is a corresponding philosophy and curriculum associated with each of these two movements that for which architectural design plays a key role in amplifying and supporting the work of students and their teachers. Architecture can also serve the educational aims even when it applies to a renovation of an existing facility, as shown in the next example.

School Renovation Study: Overall Improved Facilities and Student Outcomes

The remodeling of the Apollo Elementary School in Issaquah, Washington (Muir, 2001) provides evidence of the value improving school design, even when the improvement is simply a thoughtful upgrade of an existing facility. A few years after the Apollo Elementary School's standardized test scores had dropped to the lowest in their District, the school was identified as one of Washington State's most improved schools—with scores well above the average (Muir, 2001). What motivated this reversal? First, there was a colossal effort by staff and parents to address curricular issues and to increase the intensity of the collaborations between the community and the school. At the same time, the school was physically remodeled. That design process was a participatory one, with a three-year planning period involving teachers, parents, engineers, architects, and every one of the 600 students in the school. The physical results contained many features supporting learning as characterized by complexity theory. For example, because the new hallways were designed to be much wider than in conventional schools, there were places created where children—and ideas—could interact in informal ways. Skylights were incorporated in many rooms, allowing daylight to enter and an intimate interior courtyard created a welcoming green space for unexpected encounters.

The cost of labour and materials for this renovation was substantial: over $7 million (U.S.). But the investment appears to have been a wise one. Not only did test scores improve, but there was also much pride expressed in the renovation by staff, students, and parents. Teachers reported substantial decreases in incidents of vandalism, and a sense of purposeful intent radiating throughout the school (Muir, 2001). What we do not know is whether this sense of purposeful intent actually led to long-term differences in school culture, and whether those differences—if any—could also be tied to deeper issues, such as those considered in place-based education. But it is clear that improvements in the architectural design resulted in both measurable academic effects and more subtle influences on the students and teachers attending the school.

The Edible Schoolyard

The Edible Schoolyard is an integral part of the Martin Luther King Jr. Middle School in Berkeley, California. When the garden was started in 1995, the school cafeteria had been closed and students were buying packaged food from a shed at the end of the parking lot. The garden, founded by chef Alice Waters and former school principal Neil Smith, began as a cracked asphalt expanse. It is now a one-acre spread of bountiful organic produce. Students and teachers grow an enormous variety of crops. The fruit alone includes blackberries, ground cherries, blackcurrants, hazelnuts, figs, kiwi, mulberries, grapes, gooseberries, and raspberries. The children grow a variety of vegetables. And there are olive trees, citrus fruit trees, and apple trees. Eggs are produced by the garden's Aracana and Rhode Island chickens. Close to a thousand students attend the school, and every one of them is involved with the Edible Schoolyard.

The process of developing the Edible Schoolyard began with a design symposium involving teachers, parents, chefs, administrators, business people, students, landscape artists, and other design professionals to dream up a school garden. While the first year plantings of fenugreek, crimson clover, and vetch were growing throughout the acre and cleansing the soil, the former school cafeteria, built in the 1930s, was refurbished to become a kitchen classroom. The latter was relocated in 2001 after an earthquake retrofit, and the new kitchen classroom is now located in an old bungalow directly adjacent to the garden. The kitchen classroom also serves as a gathering place for such events as family writing nights. Together, these two learning environments—the garden and the kitchen classroom—provide a setting for students to grow, harvest, and prepare seasonal produce. As a result, they learn about principles of ecological literacy and complexity science. The garden is a site for learning about networks, interdependence, diversity, cycles, energy, succession, co-evolution, self-organization, flexibility, and stability (Capra, 1996).

In 2003, researcher J. Michael Murphy conducted a study on the effects of the Edible Schoolyard garden-based curriculum. Fifty 11-year-old children from the Martin Luther King Jr. Middle School were compared with 50 students in a control school. Sixty-four teachers from the two schools took part in the study as well. Over the course of a school year, the academic achievement scores in mathematics and science for students involved in the school garden program showed significantly greater gains than the scores of students in the control school. The students involved in the garden-based program also made greater gains in understanding cycles of ecoliteracy and showed an improved understanding of sustainable agriculture. Teachers involved in the garden-based program rated their school as more conducive to learning than the teachers in the control school, and ranked compassion for living things as one of their top three teaching priorities. This latter finding is of particular importance, as other studies demonstrate how teachers' understanding of nature-knowledge-culture systems directly influence their teaching, such as the extensive two-year study described by Glasson, Frykholm, Mhango, and Phiri (2006) with Malawian teacher educators.

Concluding Comments

This paper has explored the application of complexity theory and a corresponding architectural pattern language as a basis for school design. With the presentation of three types of examples that embody this approach, it was demonstrated that architecture is a powerful teacher. We would do well to incorporate both the overt and subtle messages that architectural design offers in the complex systems embedded in schools and the surrounding grounds in order to offer the best possible places for learning.

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Dr. Rena Upitis is a former Dean of Education at Queen's University, Kingston, Ontario, and is currently Professor of Arts Education at Queen's University. She just finished a six-year term as National Research Co-director of Learning Through the Arts, a multi-year project that brings artists to the classrooms of over 100,000 students. Her current research revolves around the ways school architecture both constrains and opens up possibilities for learning, described in a newly completed book manuscript titled Raising a School. Rena teaches courses on arts and technology, cognition, and research methods. She has worked as a music teacher in inner-city schools in Canada and the United States and has been a studio teacher of piano and music theory for over 30 years. Rena frequently presents at conferences and publishes widely in academic and professional journals. Two of her books, focus on teaching music in elementary classroom. Another co-authored book, explores ways of approaching mathematics through the arts. Rena's research has been recognized by several awards, including the George C. Metcalf Research Award (2002) and the Canadian Association for Curriculum Studies Publication Award (2005).

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