THE IMPACT OF BIOPHILIC LEARNING SPACES ON STUDENT SUCCESS

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This study is a collaboration of Craig Gaulden Davis, Morgan State University, The Salk Institute for Biological Studies and Terrapin Bright Green.

The purpose of this study is to examine to what extent the design of the physical learning space, enhanced with biophilic design, contributes to student stress reduction and improved learning outcomes for a middle school Math class at a public charter school in West Baltimore. The study presents findings of data collected from a biophilic classroom and a control classroom, where the physical design of each space varies—one is a traditional classroom while the biophilic classroom is enriched with views to nature, dynamic and diffuse daylight and biomorphic patterns. Data was collected by monitoring students' HRV (heart rate variation) as a measure of stress, comparing academic performance, student surveys, and student and instructor interviews.

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Introduction

Robust research has reinforced Edward O. Wilson's Biophilia Hypothesis that humans possess an innate tendency to seek connections with nature (Wilson, 1984). Patterns in findings have emerged linking biophilic design with attention restoration to combat mental fatigue, with stress recovery, enhanced creativity, relaxation, and excitement. Who better to benefit from the positive side effects of nature-inspired elements than students? Children spend much of their time in school when not at home and, given significant exposure to this environment, schools are an opportunity for improvement by incorporating evidence-based design that associates biophilic spaces with health and cognitive benefits. Learning spaces have the potential to impact generations through the employment of design strategies that promote early academic success and ignite a positive trajectory in a young person's life. Few studies have measured the impact of biophilic design in learning spaces and its impact on learning outcomes. However many studies reference positive correlations between biophilia, improved cognitive function, and physiological response in health-care, workplace and hospitality environments. As a result we see biophilic design being employed in these spaces. Rarely do we see it in learning spaces, and we hope to change that.

In addition, our approach was designed based on current neuroscience theory. Neuroscience literature indicates perceptual sensitivity to visual contours that are collinear, or nearly collinear is facilitated by the organizational properties of the visual cortex (Albright, 2015). Patterns with repeating lines in collinear, curvilinear and radial patterns are easily processed by the brain. These patterns are found throughout nature; some examples include veins of a leaf, branches of a tree and ocean waves. The visual ease of detecting these patterns creates a calming and sensory acuteness that should facilitate improved classroom functions.

Therefore, based on biophilia and neuroscience literature we hypothesize that biophilic design will contribute to reduced student stress and enhanced learning outcomes for a class of middle school Math students. The results will critically inform the architectural design of future learning space.

Literature Review

NEUROSCIENCE IN THE BUILT ENVIRONMENT

A longstanding question in design concerns the ways in which we might manipulate the built environment to improve cognitive performance. The modern field of neuroscience affords new opportunities to address this question through the creation of environments motivated by our understanding of human brain organization and functions, and principles of the neuronal information processing (Kandel et al., 2012). Perhaps the most pressing application for this new knowledge is school design, since the future of human civilization surely rests upon the successful education of our children.

The fundamental school design problem is this: What type of environment optimizes cognitive function – learning, memory, emotion, communication, and social intelligence – in a developing child? One neuroscientific approach to this problem is to ask what sensory information is easiest to acquire and what keeps us focused and cognitively engaged. Partial answers to these questions come from recent discoveries that reveal how visual sensory information is represented in the brain.

One of the fastest growing areas of neuroscience knowledge concerns the neuronal basis of visual perception, visual memory and visually guided behavior (Albright et al., 2000). Vision happens because light is reflected off of surfaces in the environment, refracted by the crystalline lens at the front of the eye and projected as a pattern of light onto a specialized neuronal tissue known as the retina, which lines the back of the eye. Cells in the retina convert luminous energy into neuronal energy and those neuronal signals are conveyed through a series of hierarchically organized processing stages, many of which are located in the cerebral cortex (Gilbert et al., Kandel et al., 2012).

The cerebral cortex is the largest anatomical subdivision of the human brain – approximately three-quarters by volume – and is a computational powerhouse. One-third of the human cerebral cortex – the visual cortex – is devoted to the processing of visual information, as is fitting of our functional dependence on this type of sensory information. Neurons in the cerebral cortex detect and encode various attributes of the visual world through patterns of activity in small neuronal circuits.

Many of these neurons encode a ubiquitous feature of the visual world that is fundamental to perceptual experience, namely the orientation of an image contour (Hubel & Wiesel, 1968). Contours commonly occur at the boundaries of objects, such as the edge of a table or the outline of a hand. One such "orientation selective" neuron may "prefer" a horizontal contour, while another prefers a vertical contour, such that all possible contour orientations are encoded by distinct populations of cells (Hubel & Wiesel, 1974).

Neuroscientists have also asked what is the anatomical relationship between contour-detecting neurons that prefer different orientations? It turns out that similarly oriented neurons have strong connections to one another, whereas differently oriented neurons are less well connected (Stettler et al., 2002). The orientation selectivity of these neurons, together with the biased patterns of anatomical connections, creates a network of neurons that preferentially detect curvilinear contours with smoothly varying contour orientations (Field et al., 1993). Study of human observers reveals that they exhibit exactly this type of sensitivity, as predicted by the neurobiology (Li & Gilbert, 2002).

A simple analysis of the visual image statistics of the natural world reveals that it is replete with smoothly varying curvilinear contours (Geisler, 2008). Consider, for example, the veins of a leaf, the blades of grass in a meadow, or the graceful curves of the human body. The existence of a specialized neuronal system for processing such image statistics is surely a product of the adaptive value of detecting these patterns over the course of human evolution. Without awareness of the underlying neurobiology, architects and designers have long produced patterns that possess these special image statistics, for example in the form of wallpaper patterns, cornice friezes, or radial mullions (Albright, 2015).

These patterns most commonly serve no function except aesthetic – in the case of friezes and wallpaper that are explicitly decorative and rectilinear windows are much easier to produce than round windows. These ubiquitous curvilinear features of the built environment please us. We hypothesize that one reason for this pleasure is the ease by which they are detected and structurally understood by a nervous system that evolved in the presence of such patterns (Albright, 2015). We hypothesize further that this ease of detection/understanding – this "sense of order" (Gombrich, 1984) enhances focus and allows limited sensory resources to be allocated to processing the more complex and novel stimuli that our survival depends upon – e.g. recognizing and assigning meaning and emotion to food sources and mates.

In the context of a classroom, rather than the savannas and forests in which primates evolved, the visual ease afforded by patterns that tap into the native organization of the brain should afford a relaxed and focused disposition toward the complexities of academic problems. For this reason, we predict that a classroom that features abstract visual patterns based on these neuroscientific principles should promote cognitive focus and academic success.

BIOPHILIA AND HUMAN RESPONSE

Healing and Stress Reduction

Roger Ullrich led one of the earliest studies of health-related outcomes and biophilia (Ulrich, 1984). Patients recovering from gall bladder surgery were placed in rooms along one side of a building. Half of the rooms had a view to a brick wall; the others a view to some trees and shrubs. The patients were matched by demographics and paint color of the room, so the view was the remaining variable. The patients with the view to the brick wall took an average of 8.7 days to recover, while the patients with the view to the trees took an average of 7.9 days. The patients with the view to the trees had far fewer nursing calls and took fewer pain killers.

In subsequent studies with cardiac patients in Sweden, Ulrich and his team showed patients either images of nature or blank sheets of paper before or after heart surgery. They found that patients who viewed the nature images prior to or post-surgery had lower blood pressure, lower heart rate and improved recovery times (Ulrich & Lunden, 1990).

Similarly, Peter Kahn and colleagues (Friedman et al., 2008) found that installing a video screen showing images of nature would lower blood pressure, lower heart rate and have positive psychological benefits for workers in a windowless space.

Cognitive Response

Much of the research on biophilia has focused on stress reduction as measured through heart rate, blood pressure, cortisol levels and psychological response. Another thread of research has focused on the cognitive response. As far back as the 1800s it had been theorized that the brain operates differently while experiencing nature (Olmsted, 1865). It was thought that when out in nature, the brain operates on a level of 'soft fascination'. This eventually became the basis for Attention Restoration Theory (ART), (Kaplan & Kaplan, 1989, Kaplan, 1995) which posited that portions of the prefrontal cortex quiet down while experiencing nature. After this mental pause, we have better cognitive capacity.

A recent confirmation of the ART theory came in an experiment using fMRI measurement to observe brain activity. After a stressor, participants viewed either an image of an asphalt roof top, or the same image with flowers on the roof top. Within 40 seconds of viewing the image of the rooftop with flowers, the prefrontal cortex decreased activity and subsequently the participants performed better on the recovery task (Lee et al., 2015).

There is also evidence that the presence of nature may help the rate of cognitive development among school age children. A study of 2,593 children in grades 2–4 in Spain's Barcelona school system found that, separate from demographics, children in schools with more tree canopy in the schoolyard had an increased rate of cognitive development over the course of a year of measurement (Dadvand et al., 2015).

In reality the effects of biophilic experiences are not just stress reducing or cognitive impacts but frequently a combination of both. An experiment in which participants spent five minutes seated in a windowless classroom and five minutes seated in a space with plants, a metal screen with biomorphic patterns and a view to the river outside found significantly different outcomes. The biophilic setting led to lower blood pressure, lower galvanic skin conductance, and 14% improvement in short-term memory performance (Yin et al., 2018).

Fractal Fluency

Real and simulated views of nature are not the only way to create a biophilic experience. Nature can also be represented in patterns, finishes and objects that have biomorphic forms and fractals. Fractal patterns and biomorphic forms can be identified in classical art and vernacular architecture from the column capitals of ancient Greece and Egypt, the art of Ancient Mayans, Islamic and Egyptian art, Hindu temples, Angkor Wat in Cambodia, the Eifel Tower in Paris, and the structures of Santiago Calatrava. Fractals are also evident in such well-known works as those of Botticelli, Vincent van Gogh, and Jackson Pollock.

Viewing biomorphic forms in art and architecture elicit a good visual preference response and lower stress (Joye, 2007). It may be that human brains associate biomorphic forms and patterns with living things (Vessel 2012), and these forms tend to conform to the collinear characteristics that ease visual processing (Albright, 2015; Gombrich, 1984).

Fractals can be the consecutive magnifications of self-similar patterns. These can be exact replications as in a fern leaf, snowflake or the branching pattern of an elm tree. Statistical fractals which are also self-similar patterns that are not exact repeats of each other, such as flames in a fireplace, waves on a beach and the pattern of dappled sun light under an aspen grove. There is a predictability of the occurrence of fractal design in nature (Bejan & Zane, 2012). Experiences of fractals in the built environment that have the characteristics of those most found in nature lead to measurable stress reduction responses -- heart rate, blood pressure and galvanic skin responses. Taylor and others posit that because certain fractal ratios occur so frequently in nature, that the human brain is fluent with patterns that have those characteristics (Hägerhäll et al., 2015; Taylor et al., 2016, 2017). While the statistical fractals do not have the collinear characteristics identified earlier, the response may be similar.

Research has repeatedly confirmed correlations between fractal geometries in nature and those in art and architecture (Joye 2007; Taylor 2006), but there are opposing opinions over which fractal dimension is optimal for engendering a positive health response, whether an optimal ratio exists, or if such a ratio is even important to identify as a design metric or guideline. Nikos Salingaros (2012) has examined a series of these perspectives with great clarity, noting that the range of preferred fractal dimensions is potentially quite broad (D=1.3-1.8) depending on the application. The stress reduction response, however, appears to not be limited by proximity or distance for the surface that exhibits the fractal patterns (Abboushi et al., 2019). However, at either end of the spectrum, both non-fractal artwork and high-dimensional fractal artwork have shown to induce stress (Hägerhäll et al., 2008; Taylor, 2006).

BIOPHILIA IN LEARNING SPACES

Lighting & Daylight in Schools

Some research has found that daylight does not have an impact on improved cognitive performance (Li & Sullivan, 2016). Other studies convey indirect health benefits of daylight in classrooms (Aggio et al., 2015; Eitland et al., 2018). Research suggests associations between light variation perception and mood and physiological effects that variations in light can have (Abboushi, Elzeyadi, Taylor & Sereno, 2019; Cialdella & Powerll, 1993). A study involving students from low socio-economic backgrounds investigated the impact of light levels and daylight on learning outcomes. By the end of the academic year, students in the focus lighting group showed larger gains in oral reading fluency performance than the non-focus lighting group and their improvement trajectory more closely aligned with national trends (Mott et al., 2012; Mott et al., 2014; Eitland et al., 2018). Whereas Li and Sullivan's 2016 study suggests that improved academic performance or restoration of attentional capacities may be affiliated with green views to nature rather than daylight, the Motts study attributes improved learning outcomes to daylight and light levels within the classroom. Access to good-quality and task-appropriate lighting at school is important because many classroom activities - like reading and writing - are visually oriented and form the basis of student learning (Eitland et al., 2018), thereby considering lighting as a visual aid for learning, rather than a trigger for physiological change.

Research has found that children are more sensitive to light exposure than adults because they have larger pupils and significantly greater light-induced melatonin suppression, with young adolescents having greater circadian-system sensitivity to light exposures than older adolescents (Crowley et al., 2015; Eitland et al., 2018; Higuchi et al., 2016; Lund et al., 2012; O'Hagan et al., 2016). In children, higher levels of average daily daylight exposure have also been associated with reduced weekday and weekend sedentary time and with increased levels of physical activity on the weekends (Aggio et al., 2015; Eitland et al., 2018). Access to natural daylight has been linked to greater subjective well-being, higher levels of alertness, faster cognitive processing speed, [and] better concentration performance (Eitland et al., 2018).

Effect of Surrounding Green Space on the Learner

A study completed in an elementary school in Baltimore, Maryland, reported that students find green schoolyards a safe retreat from stress because the natural areas allow students to build competence and form supportive relationships (Chawla et al., 2014; Li & Sullivan, 2016). The Chawla study references the psycho-physiological impact of direct interaction with nature and school yard green spaces. Nature immersion and its effect on creativity and human productivity, are both aspects that are considered positive qualities for a learner but which have mainly been studied either within the context of workplace design or public environments (Abdelaal & Soebarto, 2018; Shibata & Suzuki, 2002).

A Massachusetts study also investigated improved learning outcomes in relation to surrounding green landscapes. Researchers examined the relationship between [the] vegetation condition surrounding schools and school-based student performance on Math and English (Wu et al., 2014; Li & Sullivan, 2016). Using the state's standardized assessment system as a measure, they found a positive association between vegetation cover and academic performance thereby leading them to conclude that landscapes containing vegetation impact student performance (Li & Sullivan, 2016; Wu et al., 2014). Another study which shares a common focus with our study, measured high school environments including the amount of vegetation visible from classroom and cafeteria windows, the size of windows, and the density of the vegetation in each part of the campus, to predict student performance (i.e. standardized test scores, graduation rates, percentage of students planning to attend college). The findings demonstrated a positive relationship between nearby nature and school-wide academic performance (Li & Sullivan, 2016; Matsuoka, 2010).

Recalling Li and Sullivan's study, one of their most surprising findings, was the lack of difference between attentional functioning and stress recovery between classrooms with views to buildings versus no windows (Li & Sullivan, 2016). This finding suggests that views to nature play a significant role in providing students with opportunities for mental breaks throughout the class period, thereby making the case for improved attentional functioning, rather than daylight being the cause of improved learning outcomes.

Our study sought to explore effects of attention restoration and positive correlations with reduced stress over time as research has repeatedly shown that students who report lower personal and school-related stress attain higher GPAs (Gillock & Reyes, 1999), show more academic achievement (Grannis, 1992), and are less likely to engage in behaviors that lead to lower performance (e.g. truancy, dropping out of school) (Hess & Copeland, 2001).

STRESS AND COGNITION

There has been growing interest in understanding the impact of stress on students' academic performance so that appropriate interventions can be developed. For instance, (Blair, Granger, and Peters, 2005) reported that chronic exposure to financial stressors was associated with poorer cognitive performance. Other researchers discovered that chronic exposure to environmental stressors influence the academic performances of children (Haines et al., 2001). The relationship of stress and academic performance was found to be highly related to the children's stress perception (Brown, Nobiling, Teufel, & Birch, 2011). Most recently, it has been reported that African American and social and economically disadvantaged children are exposed to more stressful situations than White children (Morsy & Rothstein, 2019). In fact, African American children were 45 percent more likely to be exposed to one frightening stressor compared to Whites; 29 percent more likely to be exposed to two frightening stressors; and 21 percent more likely to have been exposed to three or more frightening stressors (Jimenez, Wade, Lin, Morrow, & Reichman, 2016). Those students who were exposed to these stressors were more likely to be unable to name letters; unable to understand a story that was read to them; unable to understand the conventions of print; had below average reading and math skills; and were unable to read a simple book independently compared to those students who were not exposed to these frightening stressors.

Methodology

To analyze the impact of biophilic design on student outcomes we focused on several effects—stress, perceptions of the learning environment, enjoyment, and math academic performance. The experimental design consisted of a classroom enriched with biophilic design enhancements and a control classroom that did not. The effects in each are compared.

EXPERIMENT LOCATION

The experiment location is Green Street Academy, a Baltimore City public charter school, located at 125 Hilton Street in West Baltimore. There are 857 students, called Scholars, in grades 6 to 12. The student body is 97% African American, 2% White and 1% Other; 97% percent receive free and reduced lunch; 29% receive special education. The school has a reputation as an innovative teaching and learning environment where teachers use project-based learning and entrepreneurship opportunities to prepare students for sustainability-oriented careers. School leaders welcomed an inquiry-based study to improve student outcomes. The design team selected middle school Math classes as the focus for the study.

DESIGN

Biophilic Classroom

The 6th grade Math class taught by Ms. Heather Bobbitt was selected as the biophilic classroom. We asked the teacher to refrain from posting excessive teaching aids on the classroom walls to give students some visual relief. Three biophilic design devices were chosen to enhance the room.

View to Nature

A garden was planted outside the window of the biophilic classroom. A variety of evergreen and deciduous plants were provided. Views to nature have been found to reduce heart rate and blood pressure (Brown, Barton, & Gladwell, 2013; Tsunetsugu & Miyazaki, 2005; van den Berg, Hartig & Staats, 2007), and improve attentiveness (Biederman & Vessel, 2006) and overall happiness (Barton & Pretty, 2010). Plants that bloom and maintain their leaves in the winter were preferred. Blooms will attract birds, butterflies, and insects and winter leaves catch the breeze. Students may notice the incidental movement outside the window and take a break from focused attention on school work to look outside. This short break seems to restore attention and allow the student to learn and remember more content (Windhager et al., 2011).

View of the Garden at the Biophilic Classroom *Patrick Ross Photography*

Dynamic and Diffused Lighting

The classroom's opaque mini-blinds were replaced with motorized, perforated, translucent roller shades operated by a solar cell. The shades were imprinted with the image of a tree shadow. Often teachers lower blinds to darken the room for projection then fail to raise the blinds when the projection ends. This robs students of daylight which can enhance learning outcomes (Heschong, 1999). The shades raise and lower automatically based on the sunlight level on the window.

The lowered shade still provides diffused daylight but is also dynamic due to the raising and lowering of shades and atmospheric changes. Dynamic and diffused lighting has been associated with positive impacts on circadian rhythm functioning (Beckett & Roden, 2009; Figueiro, Brons, Plitnick et al., 2011), and increased visual comfort (Elyezadi, 2012; Kim & Kim, 2007).

Dynamic and Diffuse Light - motorized shades with prints of tree shadow

Biomorphic Forms and Patterns

Nature-inspired patterns were provided on several classroom surfaces. A wall graphic was designed by the collaboration of Dr. Tom Albright, neuroscientist (Salk Institute), and Sara Balderi, artist (Designtex). The graphic design aligns with Dr. Albright's theory on nature patterns that are easily processed by the brain's visual system, an ability developed through evolutionary adaption. Additional patterns were provided including carpet with the print of "prairie grass"; a row of 3-dimensional ceiling tiles consisting of vertical planes carved into a wave; and the shades printed with the image of tree shadows. These patterns have been associated with observed view preference (Joye, 2007; Vessel, 2012).

Biomorphic Patterns - Carpet

Biomorphic Patterns - Wallcover and Ceiling Panel

Control Classroom - Stress Testing

Because of the limitation of only one 6th grade classroom, our control classroom was the 7th grade Math class. Admittedly, we did not control for differences in teacher and course content. But, even with these variables not controlled, the findings are interesting and valid conclusions may be drawn on the impacts of the biophilic enhanced classroom. The control classroom was enhanced by adding a neutral carpet with no pattern. Our intent was to remove the variable of acoustic absorption differences between a carpet and a hard floor. No other changes were made to the control classroom.

Control Classroom

ASSESSMENT

The project assessment included both qualitative and quantitative data in order to determine how the biophilic design impacted students' well-being (stress), enjoyment, perceptions of the physical space, and learning outcomes in math. Quantitative assessment techniques included a student stress survey, a student perceptions and enjoyment survey, biological stress testing (CorSense Sensor), and a comparison of math learning outcomes. Qualitative measures included student interviews and an instructor interview.

Student Surveys

The study used the Perceived Stress Scale for Children (PSS-C) (White, 2014) to assess the impact of a biophilic learning space on student success and perceived stress levels. It has been found that the PSS-C is a validated tool that can be used to assess the stress perception in children ages 5-18 years while discriminating between those children who are stressed from those who are not. The PSS-C was given to students in both the biophilic classroom and the control classroom near the beginning of the semester in February 2019 and at the end in June 2019.

The PSS-C consists of 13 closed-ended questions and two open-ended. The 13 questions provided students with four choices to express their feelings and thoughts during the previous week the survey was administered. For example, question 2 asks, "In the last week, how often did you feel rushed or hurried?" Students observed a simple diagram along with the options: Never, A Little, Sometimes, or A Lot and circled their choice. For scoring, choices were converted to a number—0 for Never, 1 for A Little, 2 for Sometimes, and 3 for A Lot. Seven items were considered 'stress buffers' and, therefore, were reverse-scored. Maximum score possible was 39. The higher the score, the higher the stress perception. To analyze and summarize the scores, a simple mean and standard deviation for each group and condition were calculated.

The second survey assessing perceptions and enjoyment was also given to students in both the biophilic and control classrooms. However, the survey was given only once in April of 2019. The survey included three scales or measures extracted from three, pre-existing instruments used in the learning environments research field. Perceptions of Physical Space in our survey originally came from the Structural, Physical And Campus Environment Survey (SPACES) (Zandvliet, 2014). However, we only included seven items that were relevant to our study. Examples of items are: "I have views of the outside in this classroom", and, "The amount of light in this classroom is good for me". Five items from the Enjoyment of Lessons scale were used from the Test Of Science-Related Attitudes (TOSRA) (Fraser, 1981) but the word 'math' was substituted for 'science' in the five statements. An example from the Enjoyment scale is: "I really enjoy going to math classes". The last eight items included the complete scale, taken verbatim, called Involvement from What Is Happening in This Class? (WIHIC) (Fraser, Fisher, & McRobbie, 1996) bringing the total number of items in the survey to 20. Examples from the Involvement scale include: "I explain my ideas to other students in this class", and, "In this class I learn how to solve problems".

The survey was reviewed by an expert in elementary children's reading and literacy at Morgan State University prior to using it with students at Green Street Academy. The expert recommended some rewording for the scale of Perceptions of Physical Space. This scale and Enjoyment had a 1-5 Likert response scale consisting of Strongly Disagree, Disagree, Neither Disagree or Agree, Agree, and Strongly Agree. Involvement also had a 1-5 response scale but students had to decide how often a particular practice took place and chose from Almost Never, Rarely, Sometimes, Often, and Almost Always. No items in the survey were negatively worded that would have required reverse-scoring.

Student Interviews

Research investigators interviewed three students in the biophilic classroom using a semi-structured format. Students represented low, middle and high academic performers (but investigators were not aware of who belonged in each category). Students were encouraged to assess the biophilic classroom as it compares to their other classrooms by responding to 11 questions. They were asked to evaluate specific physical affordances within the space in terms of how they impacted their well-being and learning. The interview was video-recorded as well as audio-recorded on an iPhone. The audio-recording was then transcribed verbatim into a Word document.

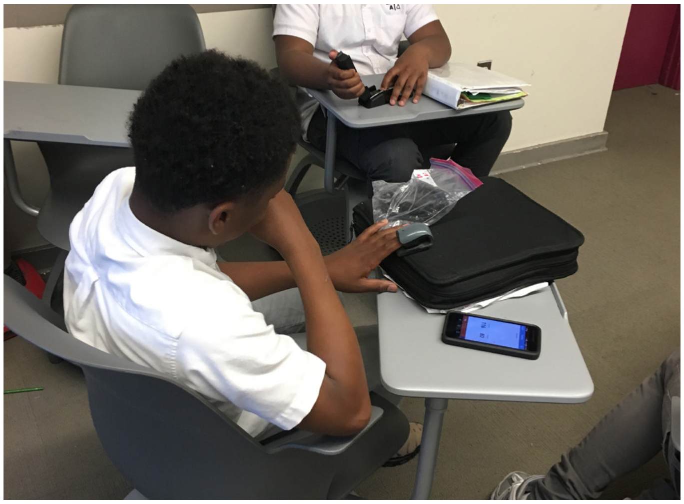
Instructor Interview

The instructor of the biophilic classroom was asked about her thoughts about the space, her observations about how the students behaved, performed, participated, their energy level and general well-being. We also asked about how the instructor felt herself and how she performed in the space. She offered her opinions on what biophilic enhancement devices had the most and least impact. The teacher's audio-recording was also transcribed verbatim.

Stress Reduction

Heart rate variability (HRV) measures the variation between successive heartbeats. A heart rate is understood in terms of 60 and 90 beats per minute. During inhalation, heart rate speeds up and slows down during exhalation—hence, the heart rate varies between 55 and 65. HRV is the measure of this natural irregularity in the heart rate. Research has shown that HRV is a stress biomarker showing changes in the autonomic nervous system. Generally, less variability in the heartbeat (low HRV) indicates that a person is experiencing high levels of stress and when the HRV is high, this is an indication of less stress and higher resiliency (Fohr et al., 2015).

The quantitative measure of stress (HRV) was assessed utilizing the CorSense Sensor by Elite HRV (https://elitehrv.com/corsense). Nineteen students in the biophilic classroom and nineteen students in the control classroom participated in the stress testing. We allowed students to adjust to each room for four months before we began stress testing. Research assistants facilitated the student testing from February 4, 2019 to May 31, 2019, three times/week, for the first minute and last minute of each class. Students inserted their forefinger or thumb into the CorSense device which provided a numerical value to a smart phone equipped with the Elite HRV application. The data was collected into a dashboard and later analyzed by researchers. Using the CorSense device resulted in 1,448 HRV tests, or data points.



Student Stress Testing - Measuring heart rate variability using the CorSense device by Elite HRV

Learning Outcomes

We compared math learning outcomes between 125 (5 classes) 6th grade Scholars in this classroom during the 2018-2019 school year with learning outcomes of 122 (5 classes) 6th grade Scholars in this classroom during the 2017-2018 school year, prior to the installation of the biophilic enhancements. The classroom, the teacher, and the course content were the same during this period; the only difference was the biophilic enhancements in the classroom for the 2018-2019 Scholars. Although the students in the two classrooms were different, their demographics such as age, race and gender distribution, socio-economic diversity, and percentage of special education students were similar. Further, as we indicate in the Findings section, both classes entered 6th grade with identical average math scores.

i-Ready

Green Street Academy uses the i-Ready test to understand the comprehension growth of Scholars in Math and Reading. i-Ready Diagnostic is a validated test offering a complete picture of student performance and growth. By adapting to student responses and assessing a broad range of skills—including skills above and below a student's chronological grade—the i-Ready Diagnostic pinpoints student ability level, identifies the specific skills students need to learn to accelerate their growth, and charts a personalized learning path for each student. Based on Diagnostic results, i-Ready reports provide detailed information on student performance by domain and aggregates data for spotting trends across groups of students.

i-Ready tests were given throughout the 2018-2019 academic year in September, December and March. Each student was assessed with a numerical score and grade level. The Scholars' gain in math comprehension from September to December to March is the metric used in this study. A comparison of the average gain in test scores and gain in grade level between the biophilic classroom (2018-2019) and the control classroom (2017-2018) were used to determine if the biophilic enhancements made an impact on math performance.

STUDENT SURVEYS

Student Stress Survey

Figure 1 summarizes the students' opinions about their own level of stress in both the biophilic and control classrooms at the beginning of the semester in February 2019 (pretest) and again at the end in June 2019 (post test). Scores on the pretest and post test ranged from 1—21 (maximum 39) for the biophilic classroom, and from 1—30 in the control classroom. The difference between the average mean on the pretest versus the post test for students in the biophilic classroom was 0.66, compared to a difference of 0.40 for students in the control classroom.

The overall distribution was skewed due to a tendency for scores to fall in the lower value direction (i.e., lower stress perception). Results also showed that more students in the biophilic classroom (67 percent) perceived their stressors to be high compared to those students in the control classroom (56 percent) in February. However, by the end of the semester, fewer students in the biophilic classroom (35 percent) perceived their stressors to be high compared to 67 percent of students in the control classroom. This finding suggests that the biophilic classroom helped to reduce students' stress levels during the semester to a greater extent than the control classroom.

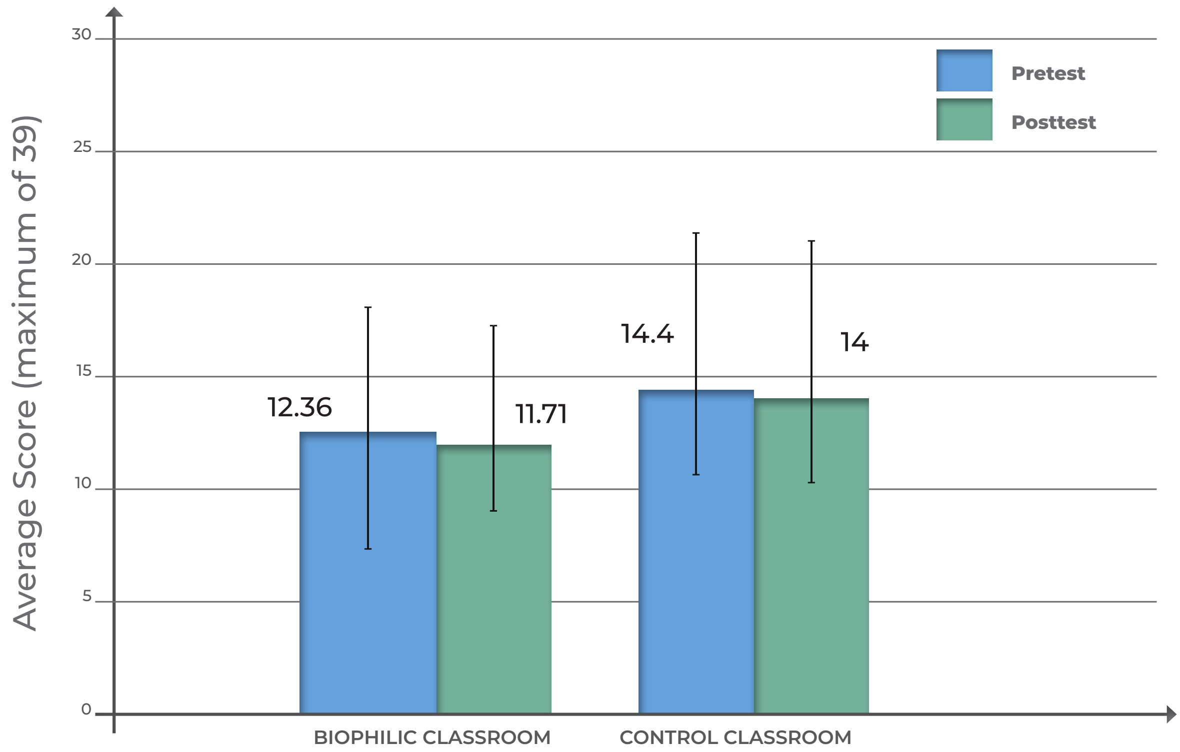


Figure 1. ***Students' opinions about their own stress level comparing the biophilic classroom (n=12) with the control classroom (n=12) at Green Street Academy, Baltimore, MD.***

Students' Perceptions of the Learning Environment and Enjoyment Survey

Figure 2 summarizes the students' responses on the survey. Average item means (maximum of 5) indicated a statistically significant difference favoring the biophilic classroom for all three scales ($p<0.01$). The control classroom had average item means below 3 for all scales, while the biophilic classroom had average item means above 4. The largest difference between the two classrooms was for the students' self-assessment of their level of Involvement (0.63).

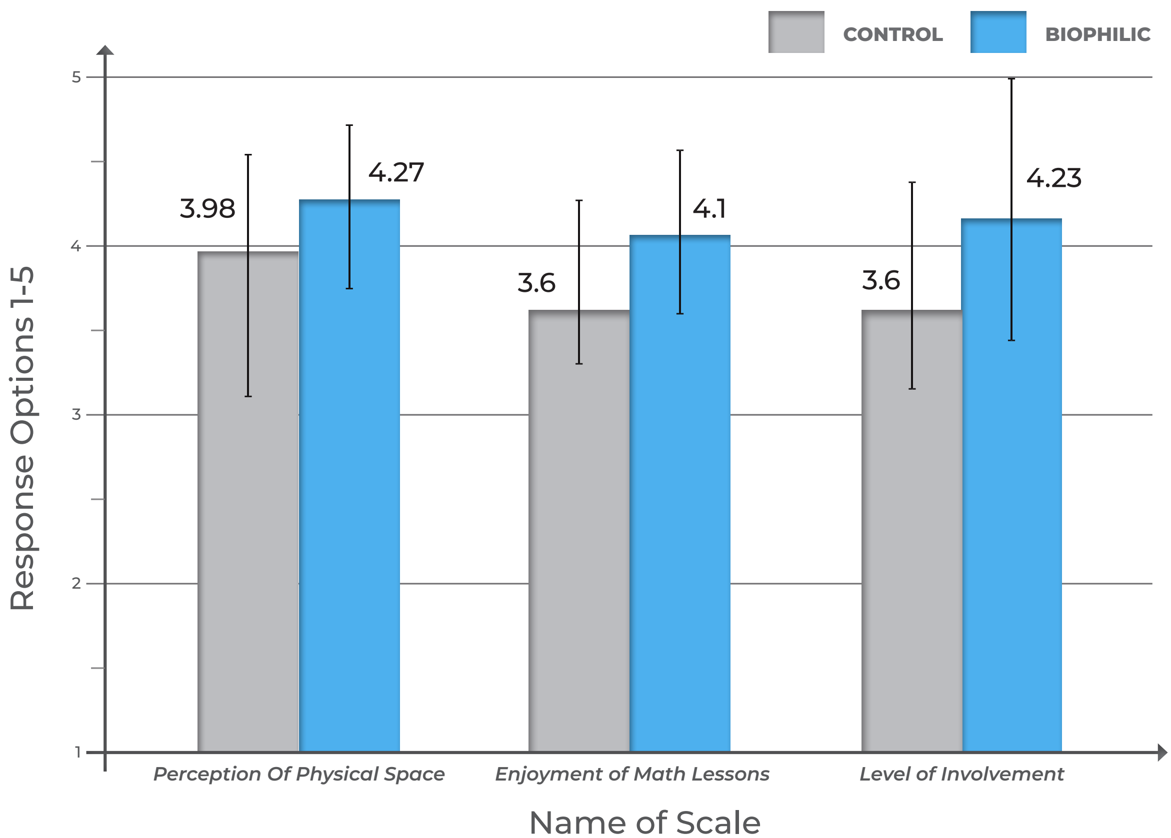


Figure 2. ***Students' survey responses with error bars comparing a control classroom (n=17) with the purposefully-designed biophilic classroom (n=16) at Green Street Academy, Baltimore, MD. Differences for all three variables are statistically significant (p<0.01).***

STUDENT INTERVIEWS

To understand the efficacy of the biophilic classroom we asked individual students a series of questions during one-on-one interviews. The teacher selected students who were low, middle and high performers in the 6th grade Math class to help reduce bias in selection. Partial transcripts of the interviewer's questions and student responses follow.

What was it like to learn in this classroom?

Sharone: Well in that classroom it's like very, it's like a nice environment. It's like a nice bright light, so it's like more, it gives me a more purpose to learn knowing that I'm in a good environment.

Casey: Well, it's comfortable and fun learning in the class, it's just the work is really hard, but the actual classroom is nice to learn in. Oh the blinds, how they go up and down automatically so there's light in it.

Irwin: Yeah, we have carpet. Is easier to run the chair through... Well, the windows are solar panels. (reference to solar motorized shades) Now it would be like cool if you do that for every classroom. It's cool.

Okay, so you got the solar blinds and the carpet. Do these things help you learn math do you think?

Irwin: It relaxes you.

How does it do that?

Irwin: Because with the light of the sun makes you concentrate better, instead of having regular lights.

The light from the sun helps you relax? But the other lights, it doesn't. Really? Have you always known that?

Irwin: Just in this classroom.

Is there anything else that you like about the math classroom that's different from other classrooms?

Irwin: The ceiling.

What about it?

Irwin: So, it's just plain like almost at the front of room, the ceiling has like little-- it look like waves.

Why do you like that?

Irwin: Because that makes me feel good... It calms me. When you turn the air on and you're underneath it cools you down, especially when it's hot.

Tell me about your stress level in the class.

Sharone: Honestly, when I go into Math class, I get very nervous because I don't like Math and I'm not really good at it, in my opinion. But now I just-- well, my stress level I wouldn't say is high. But most of the time, my stress level is very calm. Nothing really to stress about, so...

Irwin: For a test, no.

You never ever get stressed in your life?

Irwin: Yeah, I have stress for a science test.

You get stressed in science, but you don't get stressed in math?

Irwin: No

Casey: In the beginning, I'm without stress at all. But being like the middle or in the middle closer to the end, it's harder because of the work. But the classroom helps relieve the stress a lot. Along with the floors, the lighting and stuff, it just makes it easier for me to focus more and get back into what I'm doing.

It makes you more focused. How does it do that?

Casey: Because it kind of draws out the distraction and stuff that might be happening in the room so it can make it easier for me to stay focused on what I'm doing. It (stress) goes down. I can refocus and calm down. With less stress, I can get back to what I'm doing.

TEACHER PERCEPTIONS

Describe what it was like to teach in this class. What are your thoughts about this classroom?

In the beginning, it was very apprehensive because I'm a traditional teacher. I like to put a lot of stuff in the room and that was taken away from me but it forced me to find another way. As far as the room, the room is beautiful. It feels very homey, it's a comfortable space to be in. The windows, being able to get that natural light in here at different times of the day, I really enjoyed the windows. Outside, the scenery, now that it's spring, it's all nice and everything has bloomed, you can see all the trees and things outside. It's a space you can easily just get caught up staring outside and I've noticed that students do that too and they quickly kind of get themselves back together. It helps the kids that are having a difficult time and they just space out for a minute and then they come back to what's going on in the classroom. We just did our state PARCC (Partnership for Assessment of Readiness for College and Careers) test and I noticed they wanted to face the direction of the windows during testing. They all voted to face the windows so that they can look outside. I don't know if it was the swaying of the trees or whatever it was outside going on. It seems to calm them, so they were less anxious when they were taking the assessment and that part I really like because they didn't seem as tense as some other scholars are when they just have to face the wall during testing.

Did you notice anything different about the student behavior or mood?

Their mood, it just seemed like they would come in a rush and frantic and chaotic. But then, after a while, they would just kind of calm themselves down. I mean, it could be attributed to the room, it could be the lighting in here, because everything is a little softer in here.

Behavior- A lot of behavior shifts in the spring. I don't know if it's a hormonal thing or what it is but their behavior seems to shift in the spring. Sometimes for the better, sometimes it's just a little different but I think being in a setting where they are surrounded by a lack of chaos, a lack of clutter, just a lot extraneous stimuli. They kind of calm it down.

Did you notice anything different about your stress level or performance?

It is calmer in here, so a lot of times I will just turn the classroom lights off, let the natural light in and calm myself especially if it's a class that can be a little more rambunctious than the others. I will sit in a student desk and stare at the window myself if I need to. I think, "Oh, this is peaceful." I've had other teachers come in here just to calm themselves down. They will come in and say, "I actually do feel calmer in this space." Like it's really comfortable being in a space like this versus what they're normally used to.

Do you think that this classroom makes you more effective as a teacher?

Absolutely. Because I think the kids can sense my anxiety. Even with testing this year, I will say I've been teaching for a long time and the national test really causes me a lot of anxiety. This is probably the first year where I was not anxious at all for the testing. I don't even know what it was but I felt really comfortable watching them. I was not anxious, I didn't have my nervousness waiting to see the results. I felt like this year, I was very effective teaching them.

Do you think this is scalable, transferable to other grades?

Absolutely, absolutely. I think this would be probably really good in the high school setting too because high school is a very big transition time period for students and I think having an ambiance where they feel less stress and they don't feel pressured but maybe in an environment where they feel like a sense of comfort and warmth going into the classroom.

Do you think, in classrooms like this, students are less likely to be aggressive and act out?

I've heard of students who were in one class, they're very aggressive. Then they come in here and I don't see those same type of behaviors in this classroom. I'm speaking mostly where they'll be in my class and I don't have any issues and they'll go to the class right after mine or the class right before mine and they're creating chaos in the classroom.

Are you an easy teacher?

I am very tough but it's all out of love because I see a lot of potential and sometimes they don't have someone to push them to their limit. A lot of times, if they say, "I don't want to do it. I don't feel like doing it." Others would say, "Okay, that's fine". I'm not going to let you do that.

STRESS REDUCTION

Student stress was assessed using the CorSense Sensor which sent HRV data to a smart phone and aggregated the data to a dashboard. Each student was assigned their own HRV device and smart phone. Student stress level was measured at the first minute and last minute of class to capture the change in stress as an effect of the students' experience for the duration of the class. The delta between the HRV scores at the beginning of class and the end of class gives us a numerical value of the stress reduction. The larger the delta, the greater the stress reduction. Students are identified by codes, i.e. student B12 is the number 12 student in the biophilic classroom.

In Figure 3 the data of student B12 for the month of March is shown. We see the date, duration and HRV score for each test. There are usually two valid scores per day. Where there is only one score reported on March 8th this indicates there was no valid 2nd score; therefore the delta between daily scores was not used. The student's average HRV for the month, the daily HRV delta and monthly delta subtotal are noted. These data suggest that student B12 is usually less stressed after his/her experience in the biophilic classroom.

Member	Type	Date Time Start	Date Time End	Duration	HRV	HRV Average	Delta	Delta Subtotal
B12	open	3/4/2019 12:40	1st	27.117	73			
B12	open	3/4/2019 13:46	2nd	48.4102	68		-5	
B12	open	3/6/2019 10:54	1st	37.62	74			
B12	open	3/6/2019 11:25	2nd	43.7024	78		4	
B12	open	3/8/2019 12:39		55.0524	75			
B12	open	3/11/2019 12:39	1st	34.575	68			
B12	open	3/11/2019 13:48	2nd	34.4737	63		-5	
B12	open	3/13/2019 12:40	1st	38.8852	77			
B12	open	3/13/2019 13:46	2nd	39.8623	79		2	
B12	open	3/25/2019 12:40	1st	57.4512	63			
B12	open	3/25/2019 13:47	2nd	50.7476	74		11	
B12	open	3/27/2019 12:40	1st	31.72	57			
B12	open	3/27/2019 13:45	2nd	35.9231	71		14	
B12	open	3/29/2019 12:41		50.7985	65			
Subtotal						70.3571429		**21**

Figure 3. ***Raw Data - Typical Student Monthly HRV Scores***

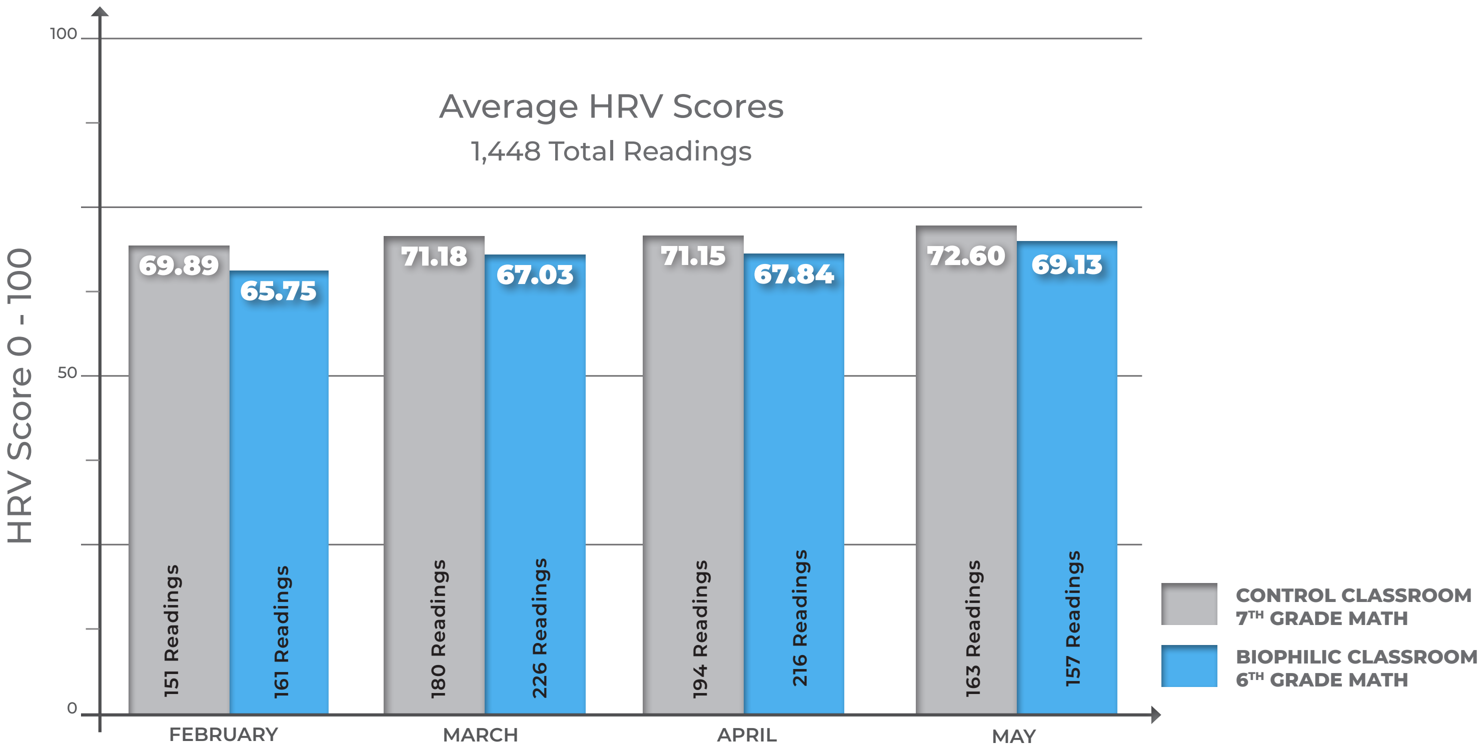


Figure 4. ***Monthly average HRV scores for biophilic and control classes***

Figure 4 indicates a comparison of the average HRV scores each month for students in the biophilic and control classrooms. Consistently, each month we see a larger HRV score for students in the control classroom. Although the difference is not significant, this indicates the students in the control classroom are subtly less stressed than the students in the biophilic classroom. HRV interpreters explain that single HRV scores can be indicative of any number of factors that make-up who we are as individuals, i.e. health, relationships, home-life, etc. But how HRV changes is reflective of the efficacy of an experience, i.e. exercise, yoga, etc. It is interesting to note that the students in the biophilic classroom are slightly more stressed initially than the students in the control classroom, but how does that stress change when exposed to a biophilic environment?

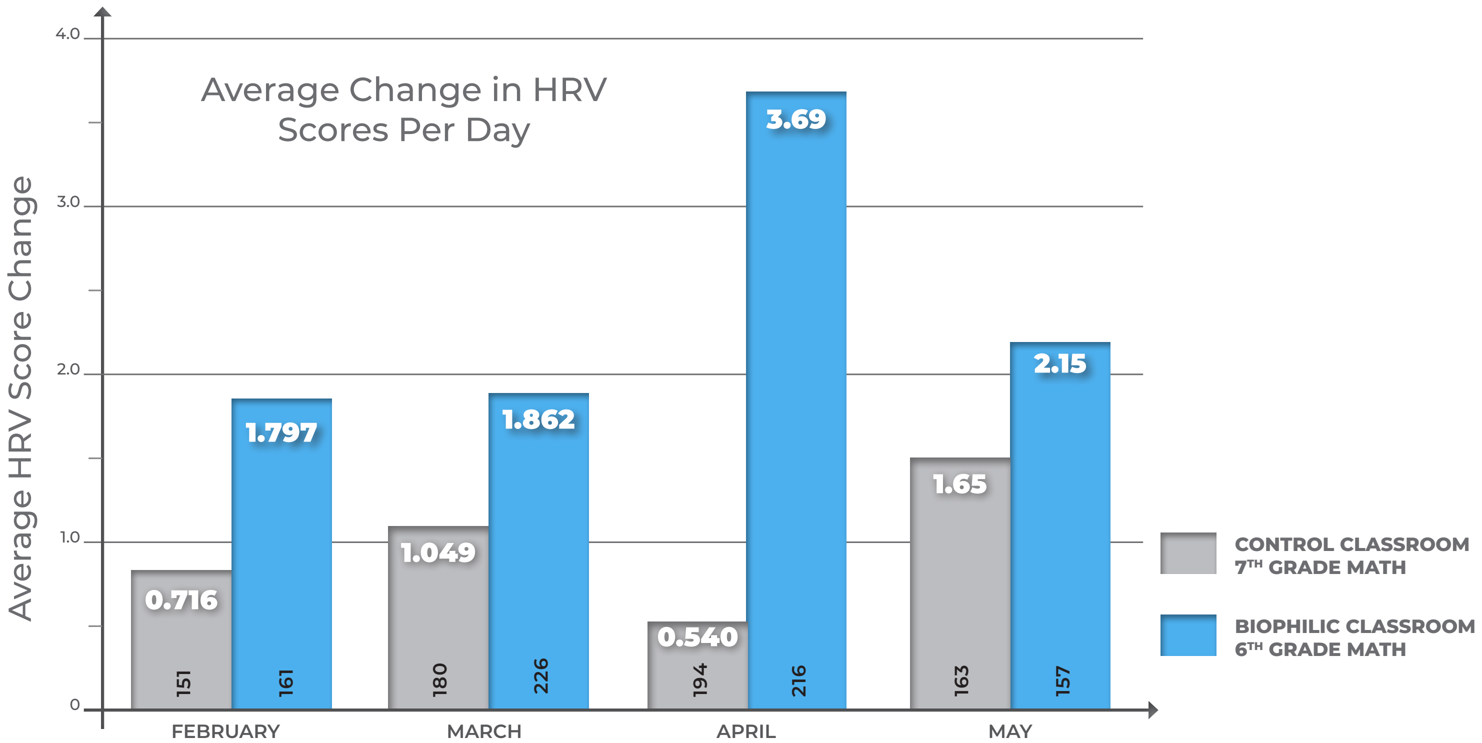


Figure 5. ***Average Change in HRV Scores per Day***

Figure 5 indicates the average daily HRV delta is significantly larger for the biophilic students indicating a significantly higher stress reduction between the start and end of each class in the biophilic classroom. Although there is stress reduction in both classrooms, the biophilic students' stress reduction is much higher. Further, it is cumulatively higher each month until its zenith in April when the delta is almost seven times higher in the biophilic classroom. We recall the teacher's interview, "their (students) behavior seems to shift in the spring" and "They kind of calm it down". Perhaps the unobstructed view to the newly blooming vegetation in April could explain the significant difference in student behavior and profound stress reduction in April for the biophilic students. The data clearly indicate for all four months of testing, the average daily stress reduction is far greater in the biophilic classroom.

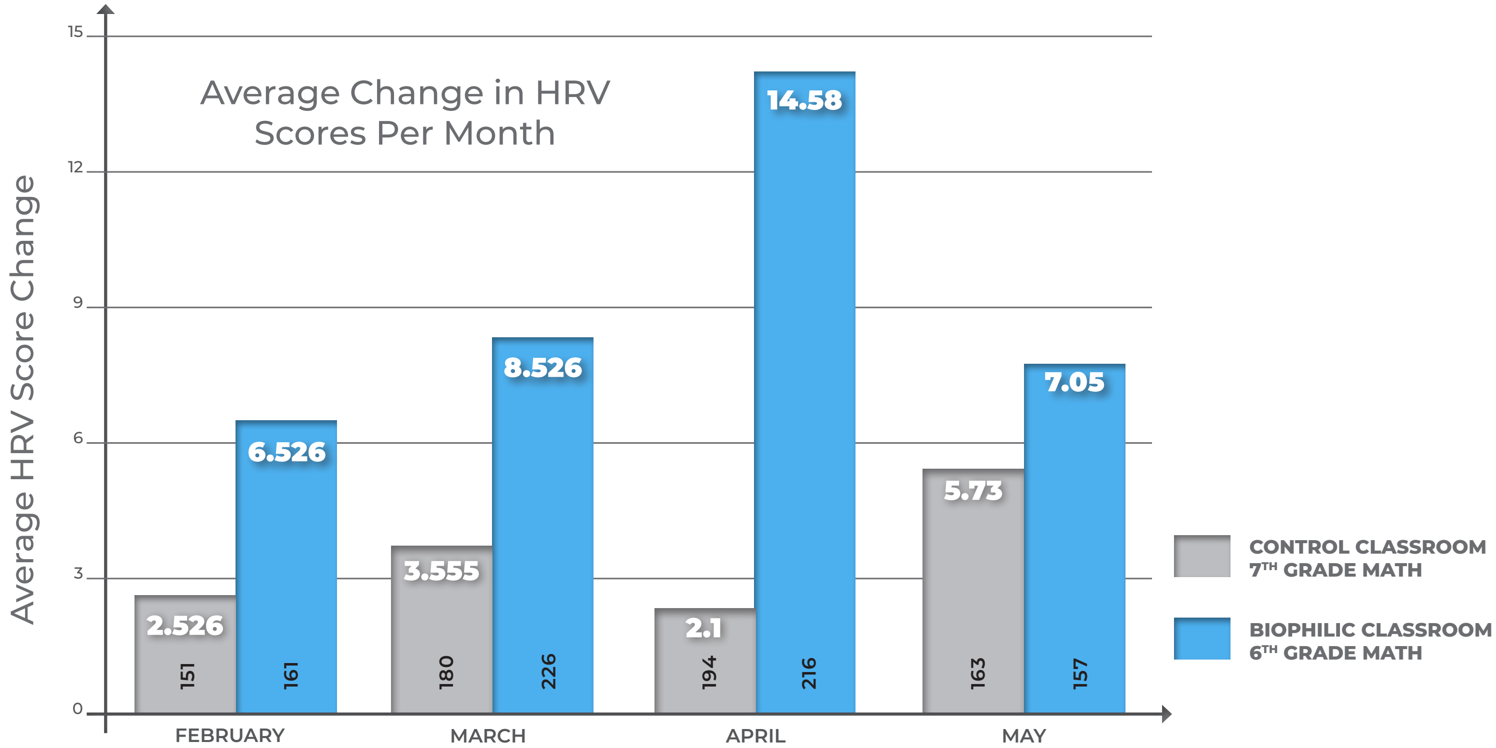


Figure 6. ***Average Change in HRV Scores per Month***

Figure 6 reinforces the data in Figure 5. The monthly average HRV score delta is significantly larger for the biophilic students. The cumulative stress reduction for students in the biophilic classroom is worthy of note.

As described in the Methodology section, we assessed math learning outcomes using the i-Ready diagnostic test. Each Scholar is assessed three times per year for Math comprehension and a report is created assigning a numerical score and grade level for each Scholar. A comparison of the average gain in test scores and gain in grade level between the biophilic classroom (2018-2019) and the control classroom (2017-2018) was used to determine if the biophilic enhancements made an impact. We want to emphasize that the only variable that has been manipulated between the biophilic and control classrooms is the biophilic enhancements made for the 2018-2019 cohort. All other variables including teacher, course content and basic room design are the same.

In Figure 7 we compare the class average i-Ready numerical test scores for the 125 biophilic classroom Scholars and 122 control classroom Scholars for tests given in September, December and March. Both cohorts have almost identical average scores in September revealing that each group enters the 6th grade with comparable Math comprehension. However, in both December and March there is a positive gain for the biophilic classroom Scholars. From September to March, the average gain in Math test scores for the control classroom Scholars is 5.48; the average gain in Math test scores for the biophilic classroom is 18.45. The biophilic classroom average Math test score gain is more than three times the gain in the control classroom.

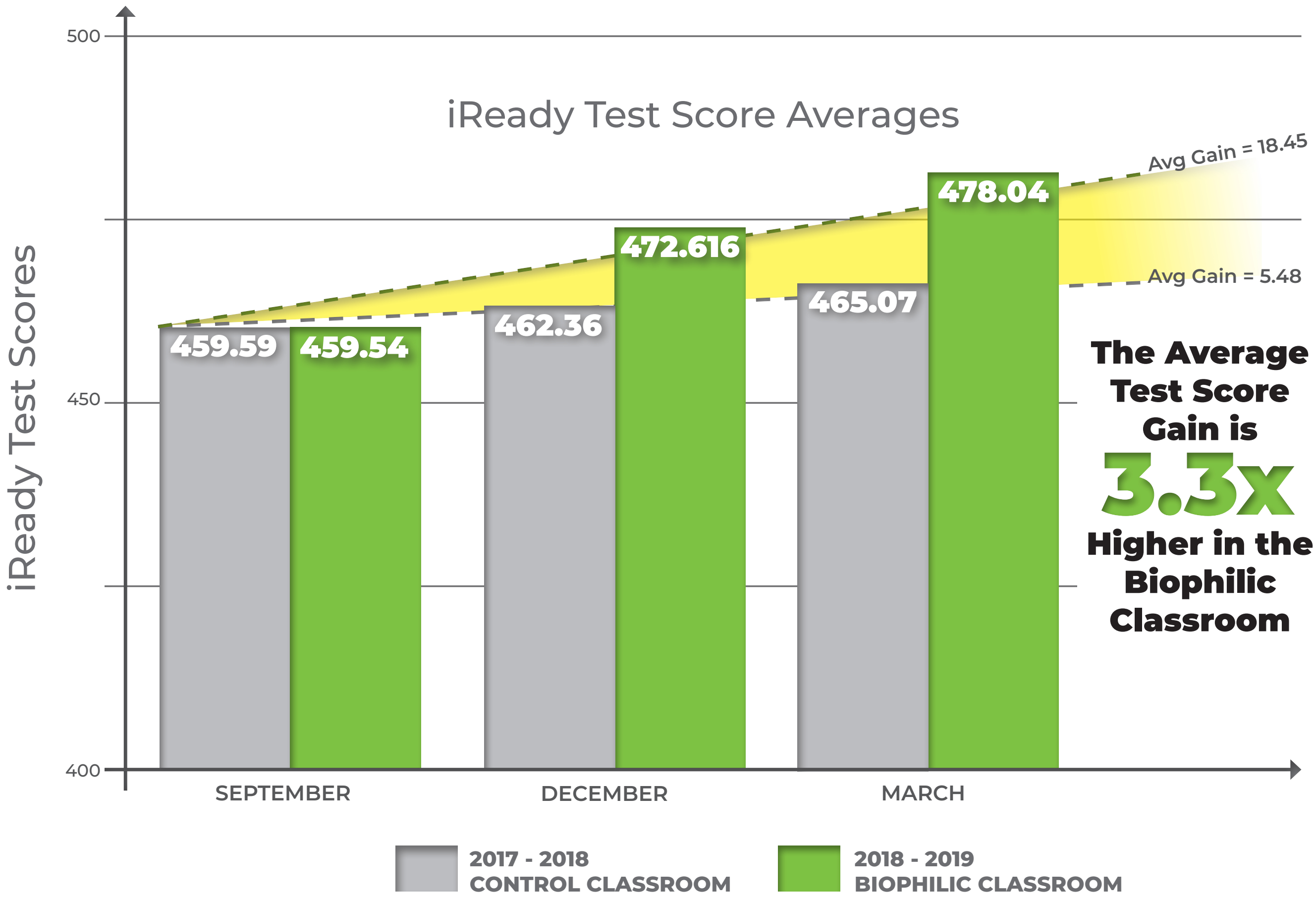


Figure 7. ***Average Math i-Ready scores for the biophilic and control classes***

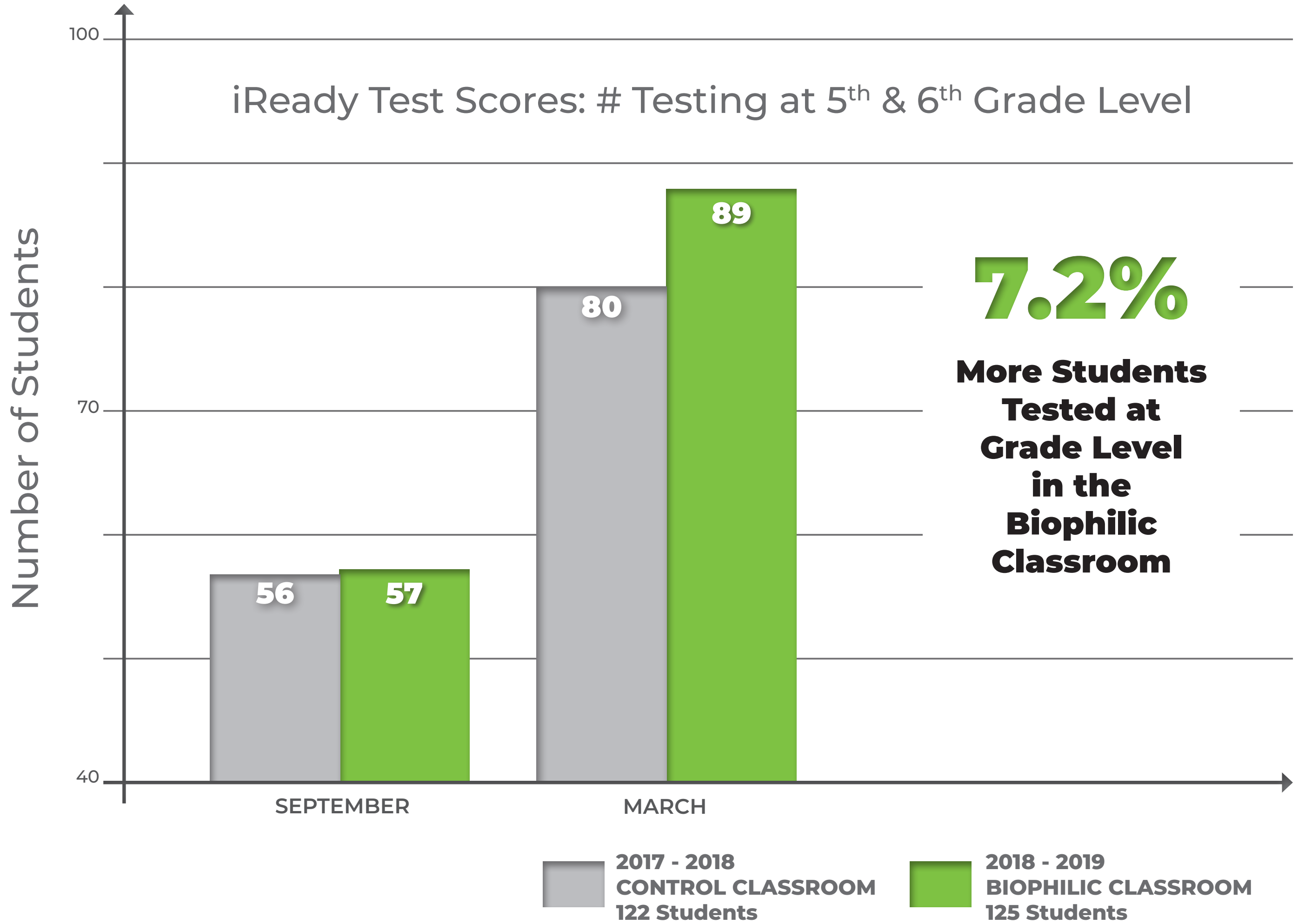


Figure 8. ***Average number of students testing at grade level***

In Figure 8 we compare the average number of students testing at Grade Level. We define Grade Level to mean students testing at 5th and 6th grade level. In September there were 56 students in the control classroom (2017-2018 6th grade Math class) and 57 students in the biophilic classroom (2018-2019 6th grade Math class) testing at Grade Level. In March there were 80 students in the control classroom and 89 students in the biophilic classroom testing at Grade Level. Nine more students, or 7.2% more students tested at Grade Level in the biophilic classroom when compared to the control classroom.

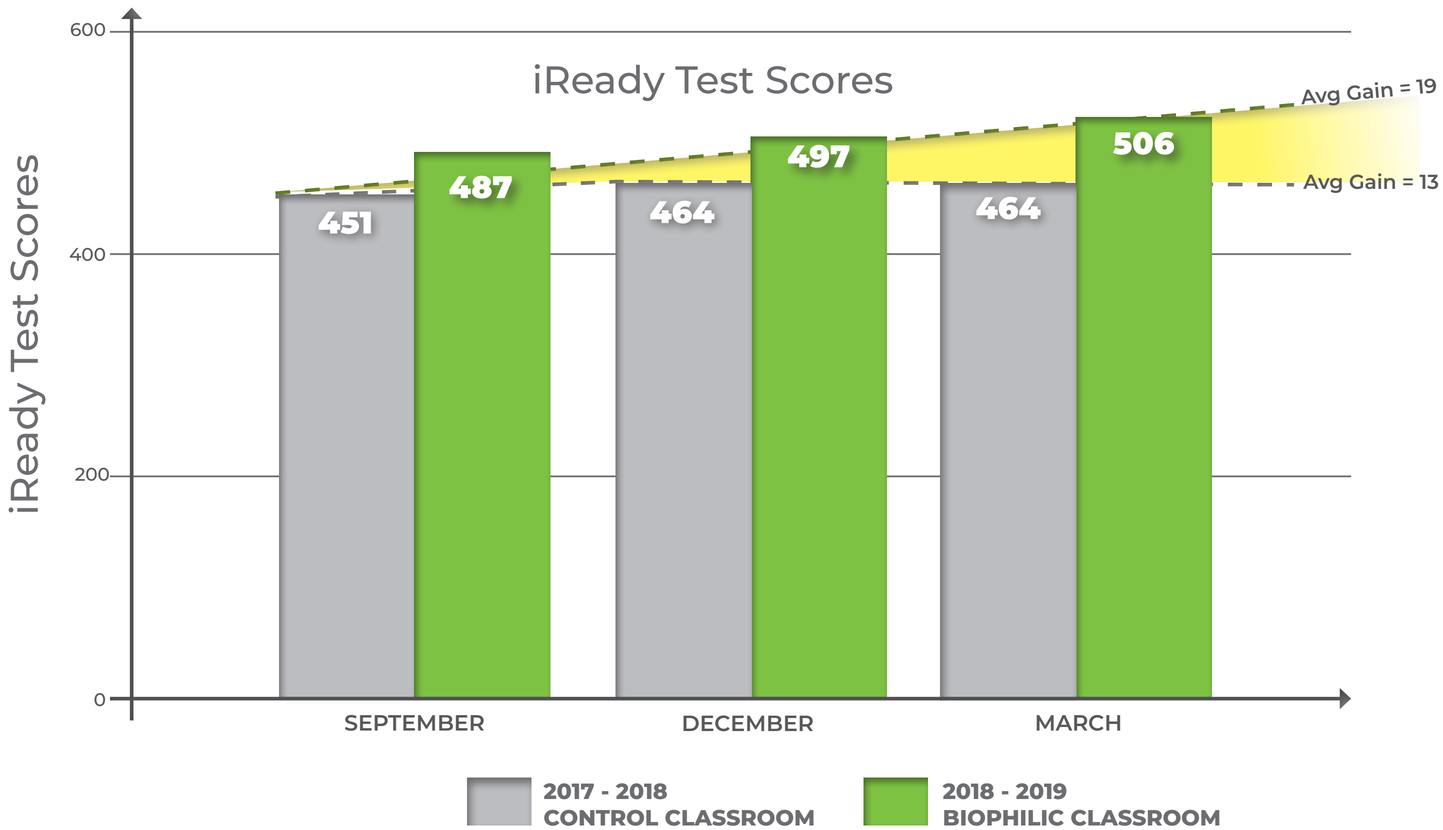


Figure 9. ***Comparison of i-Ready scores for students in the stress study***

We also compared the i-Ready scores of the students that participated in the stress study in the biophilic and control classrooms. The results are indicated in Figure 9. (r= -0.881, p <0.01, n=38). These results align with the comprehensive i-Ready analysis. In other words, the biophilic classroom students out-performed the control room students. Further, the trajectory of the gain in the biophilic classroom was continually positive while the trajectory of the control classroom was flat for the last 2 tests.

SUMMARY OF FINDINGS

This pilot study used several design devices under the umbrella of biophilic design to understand their impact on student well-being and academic success in a middle school Math classroom. Although this study is one of the first to test the effectiveness of biophilic design on learning outcomes, our findings confirm those from studies in alternate space types.

Student Perceptions

- 35% of students in the biophilic classroom perceived their stress to be high compared to 67% of students in the control classroom.
- Students felt significantly more positive in the biophilic classroom when compared to the control classroom regarding physical space, their enjoyment of math lessons, and their level of involvement.
- Students claimed to feel “more relaxed”, “calm”, “better able to concentrate”, “easier to focus” and have “more of a purpose to learn” in the biophilic classroom when compared to their other classrooms.

Teacher’s Perceptions

- The teacher identified the shades/daylight, views to nature and the classroom’s lack of clutter as contributors to student calming and attention restoration.
- The “peaceful” and “softness” qualities of the space are agents of her own reduced anxiety which made her a more effective teacher.
- The teacher hears from colleagues about the aggressive behavior of these students in classes before and after her class, but does not see this behavior in the biophilic classroom.

Student Stress Reduction

- The average reduction in student stress from the beginning to the end of class was much higher in the biophilic classroom when compared to the control classroom.

Learning Outcomes

- Improvement in average Math test scores over a 7 month period was more than 3 times higher in the biophilic classroom when compared to a control classroom.
- After 7 months in the biophilic classroom, 7.2% more students tested at grade level than control classroom students.

Conclusion

Studies have shown that biophilic environments contribute to less anxiety, reduced patient recovery time in hospitals, improved attentiveness and cognition, and positive attitudes. These studies have usually been conducted in health care and workplace environments. This study is the first research to investigate the impacts of a biophilic-enhanced learning space on learning outcomes for middle school mathematics students in an urban school. The results of our pilot project are completed. Through their responses in surveys, interviews and biometric testing, students in the biophilic classroom were less stressed than students in a control classroom. Through a series of diagnostic testing throughout the 2018-2019 academic year, the Math test scores of students in the biophilic classroom were more than 3 times better than those of students in the control classroom. In this study surveys, interviews, biometric testing, and cognitive tests all indicate the biophilic enhancements of the classroom are strongly associated with reduced student stress and enhanced learning outcomes.

RECOMMENDATIONS

- We encourage architects and learning space designers; school administrators, educators and researchers to use this report as more evidence that the design of the physical learning space contributes to the broader goals of the community. We call on education funders to increase investment in school construction and for research studies that seek to improve the student and teacher experience with the ultimate goal of higher student achievement and enhanced student and instructor well-being. We encourage education design decision makers at K-12 and higher education institutions to embrace biophilic design as another example of how the design of the space contributes to student well-being, academic success and helps put young people on a trajectory for a happier and more prosperous life.
- Next steps should include research of multiple classrooms or multiple schools to achieve more conclusive results. Individual biophilic design devices could be tested in learning spaces to identify their unique contribution. The impact of biophilic design on absenteeism could be examined. Other interesting variables may include comparing outcomes from students at colleges and universities, classes with more ethnic diversity or students with learning differences and deficiencies.
- Future studies may consider perceptions of safety in relation to biophilic design and learning outcomes. A core construct for measurement would be to investigate how a biophilic learning environment might influence stress associated with concern about bullying or perceptions of safety. Further studies should consider if the incidence of bullying or violence are reduced in a biophilic environment.

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