Learning Space Design for the Ethnically Diverse Undergraduate Classroom

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The purpose of this study is to examine to what extent the design of the physical learning space contributes to enhanced learning outcomes in an undergraduate, active learning class of ethnically diverse students. The study presents findings of data collected from two classrooms, where the course content, instructor, pedagogy and diverse student demographic characteristics are held constant, but the physical design of each space varies- one is a traditional, desks in rows, classroom and the other is an active learning, technology enhanced classroom. Data was collected by monitoring student activity via videotaped analysis of behavioral characteristics in the classroom and mapped to student performance; also by student surveys, focus group interviews and instructor interviews.

Introduction

Recently, education researchers have placed emphasis on redesigning learning spaces to better accommodate pedagogical changes (i.e., lecture model to learner-centered and group-oriented experiential model) (Alberts, 2005; Handlesman et al, 2004; Lage et al, 2004). These studies have generated evidence about the relationship between the built environment and learning outcomes. (Gensler, 2012; Brooks, 2012; Whiteside, et al, 2010; Beichner, 2008). However, no current studies have deliberately focused on the **minority majority** feature of American's future student composition. The U.S. Census Bureau projects the majority of Americans under age 18 will be non-white by the year 2018 (Frey, 2012). There are currently ten states where this condition already exists, Hawaii, Washington D.C., New Mexico, California, Texas, Nevada, Arizona, Florida, Maryland, Georgia and Mississippi (O'Hare, 2011). Since ethnic diversity is a new characteristic of the American classroom, our study will test if this changing student demographic impacts the enhanced outcomes produced by active learning classrooms in previous studies. Thus, student diversity is a unique feature of this research project.

In addition, our approach was designed to discern the specific contribution of the physical learning space to enhanced learning outcomes, using a paradigm based on experimental neuroscience approaches. The neuroscience literature indicates that "enriched" environmental complexity (increased social interactions and active exploration of the spatial environment) improves brain complexity, learning and memory in model organisms, and some studies suggest the same applies to humans (Mohammed, 2002; Diamond, 2001; Van Praag, 2000). A recently conducted brain imaging study, moreover, has demonstrated that if the learner actively controls the acquisition of new information, brain functions are significantly enhanced (Voss et al 2011 study). This directly connects neurobiological findings to a substantial body of educational research showing that learning is more robust when it moves away from a passive learning environment to one where learning happens in the social realm, with active student peer engagement (Hake, 1998; Johnson, Johnson, Smith, 1991). Thus, an "enriched" classroom environment, itself, is likely to contribute to student learning gains which are "value added" to the pedagogies employed.

The study aimed to test and understand the contribution of the physical learning space to enhanced learning outcomes. The results can critically inform the architectural design of learning spaces to better accommodate the future diverse student classroom.

Based on the neurobiological literature of environmental enrichment we hypothesized, that the enriched learning environment will correlate with increased student activity (directed movement) and engagement (with other students, with room features) and result in significantly improved learning outcomes for an ethnically diverse student group.

Since enrichment effects in the neuroscience literature are closely linked to motor behavior and exploration of the space, as well as social interactions, quantification of individual behavior and evaluation of student activity, engagement and movement in correlation with learning outcomes will be an essential component of our study. Building on most recent research on this topic performed at the University of Minnesota, surveys, instructor interviews and focus groups will also be employed as assessment tools.

Literature Review

NEUROSCIENCE

For over half a century, neuroscientists have studied the brain mechanisms for learning (Hebb, 1949; Diamond, 2001; Merzenich, Sameshima, 1993; Mohammed et al., 2002). Our brains function, based on the myriad of specific connections (synapses) between brain cell, called neurons, that form complex and ultimately highly individualized networks that represent the world around us and the way we interact with it. In order for the brain to "learn", neuronal connections and ultimately the map of their networks will have to change in ways that can be subtle, visible on the microscopic level but also large scale and measurable in patterns of brain activity that can be "imaged" with scanning devices such as MRI or PET machines (Gage, 2003; Pascual-Leone et al., 2005).

Research with animal models, ranging from rodents to primates, has provided extensive insights into the structural and molecular brain changes that take place when "learning" occurs, based on measurable behavioral change (Baroncelli et al.,2010 Hannan, 2014). In the developing brain, neuronal connections first are established, based on the environment an organism encounters when it begins to use its senses (vision, touch, hearing) and to explore its environment. For example, cats can be "taught" to ignore patterns they didn't encounter when growing up, rats lose their ability to "read" an environment with their whiskers, if these are kept clipped in early life and monkeys (as well as humans!) lose sight in an eye that is non-functional in early life. The maps of brain networks measurably change in all these instances, often on a macroscopic level.

More recently, neuroscientists have discovered that the mature brain can undergo some of the same changes, in response to learning, as seen in the developing nervous system. Much of the evidence has been generated in animal models, which show substantial rearrangement of neuronal (synaptic) communications and even the birth of new neurons, in response to cognitive demands, in brain regions deemed most important for learning to proceed (Burgess & O'Keefe, 2002; Kemperman, 1999; Mohammed et al., Sale et al., 2013).

Furthermore, a large body of literature indicates that the physical and social complexity of the environment encountered by an organism, affects its ability to perform on learning and memory tasks (Mohammed et al., 2002; Sale et al., 2013). Rodents who were housed as adolescents and young adults in cages with other members of their species and the opportunity to explore an "enriched environment" (e.g. toys to explore, things to climb onto and into) were subsequently "smarter" in learning new tasks and their brains grew more synapses and actually became slightly larger, compared to rodents housed (socially) in standard laboratory cages and especially, compared to rodents housed in social isolation (Rosenzweig, 1996). "Environmental enrichment" as described above, can even rescue or, at least ameliorate, the effects of brain injury and early adverse life circumstances (Hannan, 2014). Much emphasis is currently placed on understanding the molecular mechanisms behind the changes in neuronal communication networks with the hope that this will lead to therapeutic options for many disorders of the brain (Baroncelli, 2010; Hannan, 2014).

Thus, it is not surprising, that educators have started looking towards neuroscience for possible answers in how to enhance learning (Bryck, 2012; Clement& Lovat, 2012). Cognitive neuroscience, in particular, has been mined for its predictive possibilities in education sciences. However, there have been few attempts to experimentally test neuroscience-based concepts of learning and even fewer attempts, to connect such studies to the some of the new pedagogies that have shown to be so effective in classroom learning.

Neuroscience and architecture have a natural affinity (Eberhard, 2009; Gage, 2003). The built environment, as well as the natural environment, must be experienced and explored using our senses (sight, touch, hearing) and therefore can contribute to our mental and physical wellbeing. Architecture has also become a focal point in the new, learner centered, pedagogies that espouse interactive and group learning (Brooks, 2012). As described earlier, classrooms that encourage students to interact and move around, as they explore their subject material in an interactive fashion, are now regarded as an essential ingredient of improved learning. Interestingly, the "enrichment literature" in neuroscience, based on animal studies, has suggested that both social interactions and exploratory movement are essential ingredients of improved cognitive performance. Empirical evidence suggests that the same may apply to humans (Voss et al., 2011; Woollett, 2011).

Learning/teaching interventions based on the “enrichment” principle have already shown themselves to be successful in young children with and without disabilities (Campbell et al., 2012; Ramey, 1998; Schaaf, 2005). These data are consistent with “ergonomics of learning” postulates that educational outcomes are contingent upon appropriate learning design as opposed to innate factors (Smith, 2007) and have given rise to the burgeoning field of evidence based educational research.

LEARNING

The usual yardstick for measuring learning effectiveness is students’ academic achievement. However, reporting achievement along with students’ perceptions and opinions of the learning environment provide a more in-depth understanding of classrooms. Considering that university students spend approximately 20,000 hours in classrooms by the end of their tertiary education (Fraser, 2001), it seems not only logical but essential to an assessment process for researchers and educators to obtain information directly from students. The term learning environment, as it is used in education, “refer[s] to the social, psychological or conceptual environment rather than to the physical learning environment or space” (Cleveland, 2009; Cleveland & Fisher, 2014). However, there appears to be a shift in research towards incorporating recent developments in learning space design in higher education settings. Our study is timely because we investigated how a specially-designed active learning classroom (ALC) influenced students’ perceptions, attitudes, academic self-efficacy, grades, and behaviors during an undergraduate architecture course.

Active learning is defined as any instructional method that engages students in the learning process (Prince, 2004) so that students are not merely passive recipients of information in a teacher-centered environment. It promotes doing along with thinking. Most if not all ALCs involve less lecturing. However, active learning methods often create tension for both instructors and students (Blumberg, 2009; Weimer, 2002), and they still tend not to be used in colleges and universities. This is likely due to a “…general bias in favor of the traditional classroom paradigm…” (Gislason, 2010, p. 46) and a “class-centered notion of education tied to the familiar grammar of schooling which is predicated on the assumption that a single teacher is in charge of a standard-size classroom” (Gislason, 2010, p. 130). Despite the tensions, recent research has shown that students prefer in-class active learning environments (Bleske-Rechek, 2002; Meyer, 2013), and their academic performance is improved (Brooks, 2011; Cotner et al., 2013; Freeman et al., 2007; Knight & Wood, 2005; Yoder & Hochevar, 2005; Yuretich, 2004).

Uncovering students’ perceptions along with measuring learning outcomes, are important for understanding the effectiveness (or ineffectiveness) of active learning strategies. In Welsh’s (2012) study in Vancouver, B.C., Canada, responses on two survey questions were analyzed from a sample of 260 science and mathematics undergraduates. Specifically, students were asked to rate the importance of in-class active learning strategies (use of clickers and group discussions) using a 5-point format consisting of Unimportant to Very Important. Secondly, they were asked to comment on their rating. Results showed that “females and students in their second and third year perceive in-class active learning techniques as more important to positively influencing their academic performance in lecture” (Welsh, 2012, p. 82).

Mount St. Mary’s College in Los Angeles conducted an active learning study in a molecular biology course (Nogaj, 2013). Lecture halls were converted into ‘studio’ classrooms consisting of several round tables, moveable chairs, several LCD projectors and desktop computers, a large display screen, and a SmartBoard. Student performance was compared when the course was taught in the studio or ALC versus a traditional lecture-based room. The author concluded that on the final exam, “students performed equally well or better when active learning was used” (Nogaj, 2013, p. 54). However, we feel these results can not be solely attributed to the ALC because there were too many pedagogical and assessment differences between the two classrooms.

Technology often plays a large role in ALCs. For example, in a three-year study at the University of North Carolina, educational technology called Echo360 was used in a pharmaceutics course required for all pharmacy doctoral students (about 150 per year). A professor taught the course using traditional lecture with PowerPoints in 2011, and then in 2012 and 2013, flipped the class and videotaped lectures, used clickers, and had students work in pairs for discussions. Student academic performance on the final exam improved by 5.1 percent over the 3-year period. Interestingly, before the pharmacy course began, 75 percent of students said they preferred lectures but 90 percent preferred the flipped model after experiencing the ALC (Meyer, 2013).

LEARNING SPACE

Acknowledging the long history of the study of neuroscience and learning, research on the impact of space on learning is more recent. The studies upon which our research builds begin with SCALE-UP, Beichner' s study at North Carolina State University. This study concluded that the development of an active learning pedagogy in a space that affords student collaboration produces superior learning outcomes when compared with a traditional (desks in rows) environment and lecture teaching style (Beichner et al., 1999). "Social interactions between students and with the instructor appear to be the active ingredient" (Beichner, 2008) in the active learning classroom which produces a far better conceptual understanding than students in the traditional lecture classroom. The TEAL (Technology Enabled Active Learning) studies at MIT adopted the same model to improve a 40%-50% attendance rate and 10% failure rate in physics lectures (Dori et al., 2003). MIT found "the social aspect was important in the construction of knowledge and contributes to establishing new insights and sharing knowledge with peers" (Dori & Belcher, 2005), as the failure rate was cut to 5% and, like SCALE-UP, student conceptual understanding was significantly improved in the active learning classroom.

Steelcase Education Solutions took the approach of having the same students experience both the traditional classroom and the "new" active learning classroom. Students rated the new classroom superior on twelve scales in a self-report survey; collaboration, focus, active involvement, opportunity to engage, repeated exposure to materials through multiple means, in-class feedback, real life scenarios, ability to engage ways of learning best, physical movement, stimulation, feeling comfortable to participate and creation of enriching experience (Scott-Webber, Strickland, & Kapitula, 2013).

However, the above studies did not focus solely on space as the contributor to enhanced learning outcomes. University of Minnesota (UMN) studies were the first to provide evidence demonstrating that space alone affects learning. UMN built on the design of SCALE-UP and TEAL but held the pedagogy constant in both classrooms. In fact, only the physical space varied so the effect of the space alone could be isolated. UMN found that students in the active learning classroom outperformed their counterparts in the traditional classroom when comparing students' average grades versus average ACT scores in each class (Brooks, 2010). In a later study, UMN varied the pedagogy in both classrooms and found negative reaction from both students and instructor when pedagogy did not match the space (Walker, Brooks, & Baepler, 2011). UMN also examined the impact of different physical spaces on instructors and students. This study concluded space shapes instructor behavior and classroom activity; further the traditional classroom encourages lecture pedagogy at the expense of active learning and conversely the active learning classroom marginalizes lecture while promoting active learning (Brooks, 2012).

Armed with this knowledge of how learning spaces impact student performance, we now see an emerging change in student demographics. The American undergraduate classroom is becoming demographically diverse. Both SCALE-UP and UMN studies indicate future investigations should consider do students respond differently to the contributions of formal learning environments based on demographic characteristics?(Beichner, 2008; Brooks, 2010). This pilot study built on the University of Minnesota model to evaluate how space contributes to the learning outcomes for a demographically diverse class of students at a Historically Black Institution (HBI).

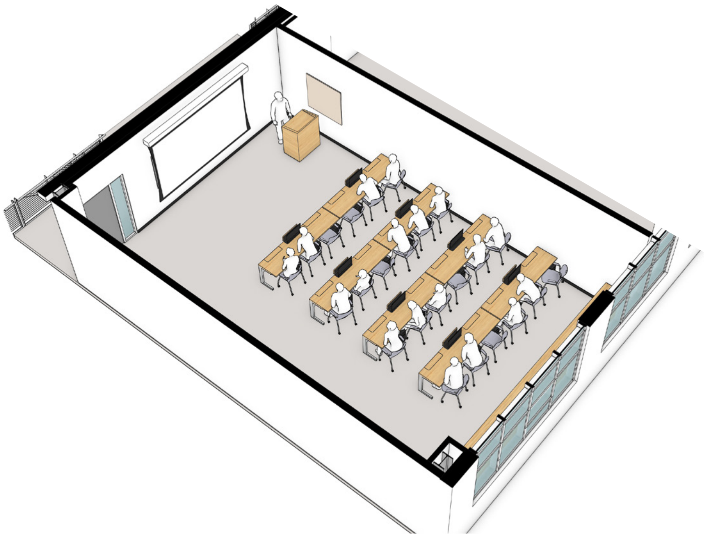
Methodology

In order to isolate the effect of only the physical space on learning we built on the research of the SCALE-UP and TEAL projects, as well as recent research by the University of Minnesota, and designed an experiment using two classrooms, one Traditional Classroom (TC) and one Active Learning Classroom (ALC). Only the physical design of each room varied while other variables were held constant. The instructor, pedagogy, student diversity, course content, time of day the course was taught were the same in both classrooms. The students were third year undergraduates majoring in architecture. The course taught was entitled Design and Human Behavior, which is an elective within the School of Architecture and Planning at Morgan State University, a Historically Black University. The pedagogy was consistent in both classrooms and consisted of lecture, group discussion, group projects, group presentations and quiz. The time of day for each class was 9:30am- 11:00am; students in the traditional class met on Mondays and Wednesday, the students in the ALC met on Tuesdays and Thursdays.

The unique quality of this research is the diversity of the students. There is ethnic diversity as students described themselves as African-American, White, Hispanic, Asian and students from Europe, Asia, South America and Africa. Students were both U.S. citizens and immigrants. There were transfer students and students that began their academic career at Morgan State. There was a wide range of socio-economic backgrounds among the students.

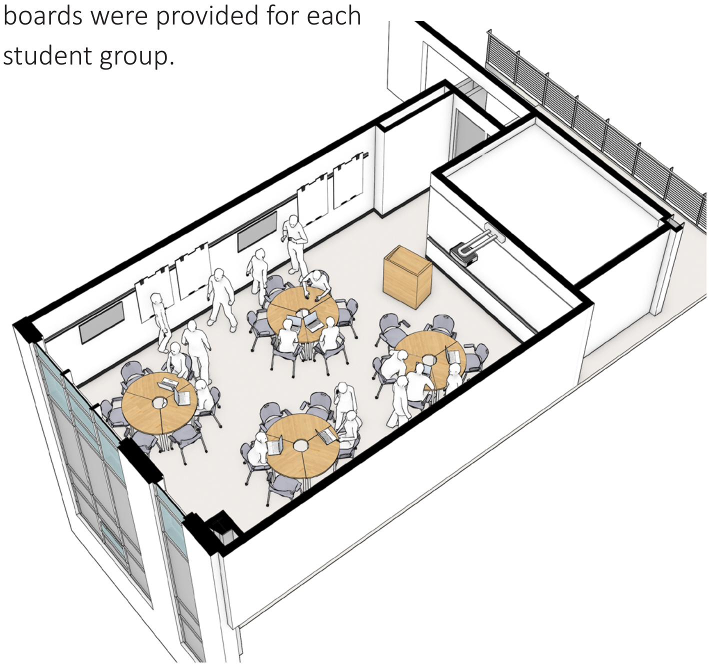
LEARNING SPACE DESIGN

The traditional classroom features rows of desks with computers embedded in the furniture. The instructor has control of the student computer use. During the first semester the classroom had a center aisle, for the second semester the classroom had a side aisle. The instructor at the front wall controlled the projection. White board surface is provided at the front wall only. The exterior wall is primarily windows with blinds.



TRADITIONAL CLASSROOM

The active learning classroom contained Herman Miller round tables and chairs for four groups of six students at each table. Three pieces make one round table for six students. Tables and chairs were on casters and chairs swiveled. Each student group had one wall-mounted monitor controlled by their personal device, i.e. laptop or tablet. Wall mounted white boards boards were provided for each student group.



ACTIVE LEARNING CLASSROOM

ASSESSMENT

Neurobehavioral Analysis

Video recordings of each classroom setting were conducted using three camcorders in each classroom. These camcorders were mounted such that the entire classroom could be viewed from different angles and recordings were made throughout the entire class time. Video-footage was archived for future analysis using a unique software program (CleverSys, TopScan) that typically is used to quantify behavior in neuroscience animal studies.

Two graduate students (henceforth referred to as raters) from the School of Architecture and Planning at MSU conducted the analysis of the video tapes. Prior to the analysis, inter-rater reliability was established to be better than 90%. The raters selected a total of 10 hours of class time from throughout the semester, from each of the two different learning environments. Time samples for analysis were taken from 10-minute periods from near the start and near the middle of the instructional periods and represented identical coverage of subject material/ classroom exercises in each classroom environment. Individual students in both classrooms were given a code number by the raters, who were blind to the students' identity. Behavioral variables as identified below, were rated by using specific key stokes on the computer key board previously programmed into the CleverSys software.

The following behavioral variables were measured for each student on the basis of seconds engaged in each activity over the 10 minute (600 second) rating period.

1. Movement: student out of his/her seat, moving in the classroom space (to another student group, etc.)

2. Student to Student Interaction: Student engaged on course content related conversation with another student or showing joint attention on a group task;

3. Instructor/Material Interaction: Student focused on the instructor or, individually, looking at material assigned by the instructor (e.g. movie, reading, board)

4. Interaction with the Built Environment: Student interacting with room features such as white boards, technology or presenting with a projected image in front of class

5. Disengagement: Student clearly not engaged with the instructor, class material or another student (activities such as looking out of window, staring "into space", "sleeping" on desk, checking cell phone etc.)

The average period (mean) engaged in each of the 5 variables for each student was calculated using an Excel spreadsheet. Statistical analysis comparing overall student behaviors in the active learning classroom and the "traditional or standard" classroom was conducted using the SPSS software program.

Student Survey

Students were surveyed individually at the end of the semester. Surveys were completed on-line outside of class or by hand in class. The survey results were analyzed as a comparison of twelve measures of the learning environment and students' attitude to the subject and academic self-efficacy.

Scales from four valid and reliable learning environment instruments used previously with thousands of students and in dozens of countries, were used to create the survey for this study. Each scale contained five items that were chosen by consensus among the researchers. In addition, five items were modified from Fraser's (1981) Test Of Science-Related Attitudes—TOSRA, along with five items assessing students' academic self-efficacy (Jinks & Morgan, 1999). Lastly, a new scale was created to meet the unique focus of this study on learning space. In total, the Architecture Learning Environment Survey—ALES has 14 scales with 70 items.

All seven scales were used from What Is Happening In this Class?—WIHIC (Fraser, Fisher, & McRobbie, 1996). The scales are called Student Cohesiveness, Instructor Support, Involvement, Investigations, Task Orientation, Cooperation, and Equity. All items are positively-worded eliminating the need for reverse-scoring. Barnette (2000) revealed that reverse-scoring was not an effective strategy to reduce respondent complacency and recommended using directly-worded stems with bi-directional response options. Taking heed of this recommendation, all items in the ALES are worded so that none of the items needed reverse-scoring.

One scale was used from the College and University Classroom Environment Inventory—CUCEI, namely, Innovation, (Fraser & Treagust, 1986), and one from the Constructivist Learning Environment Survey—CLES, namely, Personal Relevance (Taylor, Dawson, & Fraser, 1995). Two scales called Open-Endedness and Material Environment were used from the Science Laboratory Environment Inventory—SLEI (Fraser, Giddings, & McRobbie,1995). We used five out of seven possible items from Material Environment but three of these items became part of a 'new' scale we named Physical Space. We felt Physical Space more accurately described the scale in the context of an architecture course. Wording for the items from the SLEI were modified two ways; (1) 'laboratory' was replaced by 'classroom', and, (2) no reverse-scoring was necessary (e.g., "I am ashamed of the appearance of this laboratory" became "I like the appearance of this classroom.") We then created two new items for Physical Space and three new items for Material Environment. The five 'new' items were provided by a Herman Miller education survey.

Table 1 provides more detail on the specific scales extracted from the four surveys. The table indicates the name of the scale, a description of the scale, and provides a sample item. Table 2 describes the nature of two scales on the ALES that specifically address the design of a classroom.

Table 1. *Descriptive Information for Learning Environment Scales on the ALES**

SCALE NAME	DESCRIPTION	SAMPLE ITEM
WIHIC		
Student Cohesiveness	Extent to which students know, help, and are supportive of one another	I make friendships among students in this class.
Instructor Support	Extent to which the instructor helps, befriends, trusts, and shows interest in students	The instructor takes a personal interest in me.
Involvement	Extent to which students have attentive interest, participate in discussions, perform additional work, and enjoy the class	I discuss ideas in class.
Investigation	Emphasis on the skills and processes of inquiry and their use in problem solving and investigation	I carry out investigations to test my ideas.
Task Orientation	Extent to which it is important to complete activities planned and to stay on the subject matter	Getting a certain amount of work done is important to me.
Cooperation	Extent to which students cooperate rather than compete with one another on learning tasks	I cooperate with other students when doing assignment work.
Equity	Extent to which students are treated equally by the instructor	I get the same amount of help from the instructor as other students do.
CUCEI		
Innovation	Extent to which the instructor plans new, unusual class activities, teaching techniques, and assignments	Innovative technology is used in this class *(new item for this study).*
CLES		
Personal Relevance	Extent to which subject is relevant to students' everyday out-of-school experiences.	I learn how architecture can be part of my out-of-school life.
SLEI		
Open-Endedness	Extent to which the classroom activities emphasize an open-ended divergent approach to investigation	During class activities, other students collect different data than I do for the same problem.
Material Environment	Extent to which the classroom equipment and materials are adequate.	I find that the classroom is NOT crowded when I am doing activities.
NEW SCALE		
Physical Relevance	Extent to which the classroom space promotes effective learning	I am able to see all the students in this class.

Response options for all items were 1-Almost Never, 2-Seldom, 3-Sometimes, 4- Often, and 5-Almost Always
*Additional scales were Attitude and Academic Self-Efficacy

Table 2. *Scales From the Architecture Learning Environment Survey That Specifically Address the Design of a Classroom*

NAME OF SCALE	ITEM	SOURCE
Physical Space	I find that the classroom is NOT crowded when I am doing activities.	SLEI[1]
	I like the appearance of this classroom.	SLEI
	This classroom has enough room for both individual and group work.	SLEI
	I am able to see all the students in this class.	Herman Miller[2]
	I have no problem hearing the instructor in this class.	Herman Miller
Material Environment	I find the seating comfortable.	Herman Miller
	I have an adequate amount of surface space to do my work.	Herman Miller
	I am encouraged to move chairs, tables, and other things to help my learning.	Herman Miller
	The equipment in this classroom is in good working order.	SLEI
	The equipment and materials that I need are readily available.	SLEI

[1] Science Laboratory Environment Inventory (Fraser, Giddings, & McRobbie, 1995)
[2] Herman Miller Education

Learning outcomes

Grades

Individual student grades were compared to their Grade Point Average (GPA) to evaluate student performance in this class compared to the expectation of the outcome.

21st century skills

Regardless of physical learning environment, research suggests that an active learning pedagogical approach can help students build the mindset and skillset needed to thrive in the 21st century. The skillset has often been described as the 4 “C’s”, Collaboration, Creativity, Critical Thinking, and Communication.

Therefore, as part of this study, the instructor sought to foster learning experiences in both the traditional learning environment and active learning environment that would offer students the opportunity to develop the mindset of a collaborator, creator, critical thinker, and communicator.

The instructor sought to understand through consistent observation the impact certain activities might have on students who seemed to struggle with practicing the 4cs mindsets in demonstrable ways in class, and those who seemed to excel in the 4C’s; and by extension, understand the degree to which the learning environment supported or enhanced those activities designed to foster the 4Cs.

The instructor chose 2 students in each class to follow based on his own assessment of their ability to apply the 4Cs in the first 2 weeks of course work. The sample size of 2 was chosen simply based on the instructor’s limited capacity to follow students beyond teaching the course. Given the focus on diversity in the study, the sample was intentionally diverse: 2 females, 2 males, 2 African Americans, 1 Latina, and 1 Caucasian.

To assess progress, the instructor noted the degree to which each of the 4 students displayed these “4C” skills.

Student Focus Group and Individual Student Interviews

Research investigators interviewed students in groups of two or three. Five students were also interviewed individually. Students were encouraged to assess the space and specific physical affordances within the space, in terms of their engagement, enhancement of their learning experience, enrichment of instruction, flexibility and alignment between space and course content.

Instructor interview

The instructor was interviewed to assess the learning space in terms of efficacy of layout, scale, furniture and technology and their impact on his behavior, his movement, the pedagogy and student learning.

Findings

This section summarizes the valid records of 49 students enrolled in the Design and Human Behavior courses in the Spring and Fall semesters of 2014. Table 1 below shows the distribution of students in the active learning and traditional classrooms.

Table 3. *Distribution of Students by Class*

CLASSROOM	NUMBER OF STUDENTS
Active	20
Traditional	29
Total	49

Student Demographic Information

Most of the students in the two classes were males (61%), which is quite typical of architecture programs across the United States. Table 4 describes the gender distribution pattern.

Table 4. *Gender Distribution by Class*

GENDER	TYPE		TOTAL
	ACTIVE	TRADITIONAL	
Male	13	17	30
Female	7	12	19
Total	20	29	49

This study's unique contribution to the literature on active learning environments is the racial/ethnic composition of the survey sample. Compared to other research projects, the Hord Coplan Macht/Morgan State University study examined whether diversity impacts the learning outcomes of active learning classrooms reported from previous studies. Our study sample includes African Americans, Whites, Latinos, Multiracial and International students, (Figure 1). A little less than half of the students identify themselves as Black (48%), International (17%), White (14%), Hispanic (12%) and Multiracial (9%).

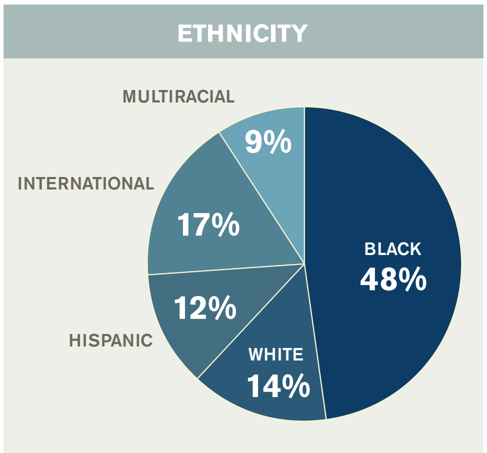


Figure 1. *Ethnicity of Students Across the Two Classroom Environments (Active Learning and Traditional) in ARCH 305: Design and Human Behavior*

Academic Information

Exactly half of the students in the sample were transfer students and half are native, or those who started at Morgan as freshmen. This is an important characteristic because the 2014 National Survey of Student Engagement reports that senior transfer students perform less well in collaborative activities than their peers who started university life as a freshman. (National Survey of Student Engagement, Annual Report, 2014, p. 10).

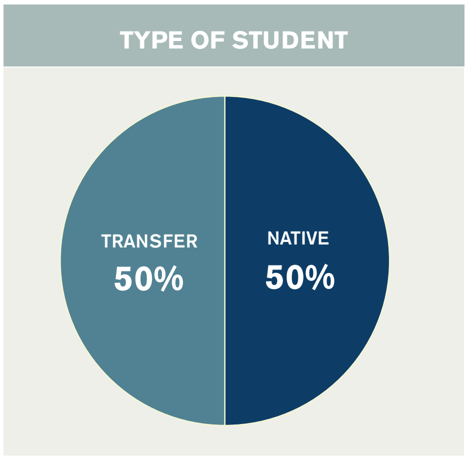


Figure 2. *Percentage of Transfer Students Versus Native Students (Started at Morgan State) Across the Two Classroom Environments*

NEUROBEHAVIORAL ANALYSIS - SOCIAL DOMAIN

Using the CleverSys Topscan manual coding system to analyze the videotape recordings, the following key results support the study's notion that there is a difference in student and instructor behavior between the active learning and traditional classrooms for the two semesters.

Student to Student Interaction

The duration of time that students interacted with fellow students is significantly different in the two classrooms (p=21.92, p>.015). Students in the active learning classroom interacted with each other at an average of **147.42 seconds per interaction**, compared to those in the traditional classroom who interacted with each other at an average of **88.51 seconds per interaction.**

Student to Instructor Interaction

The interaction between students and instructor was significantly higher in the traditional classroom (p= 1.014, p> .05). Students in the active learning classroom engaged with the instructor at an average of **337 seconds per interaction** compared to those in the traditional classroom who interacted with the instructor at an average of **414 seconds per interaction.**

These results are to be expected. As students engage more with each other they will naturally interact with, and rely on the instructor less. More student-to-student interaction suggests students are actively engaged in their own learning, which historically has meant more robust learning leading to enhanced learning outcomes.

Another view of these data is to look at the total sum of minutes students were engaged with each other and with the instructor during the entire sample period. Summary data (means) for all students in each of the classrooms are shown graphically for two seminal indicators of student active versus traditional learning engagement. Here we show two separate data sets for the spring 2013 and fall 2014, since the classes in the spring and fall were taught by different instructors. It is remarkable to note, how consistently the built environment shapes the change in student/student and student/instructor interactions across the two different semesters and instructors, in particular, as these instructors had somewhat different instructional styles. **This suggests that the physical learning space exerts a powerful additive effect on employing active learning pedagogy.**

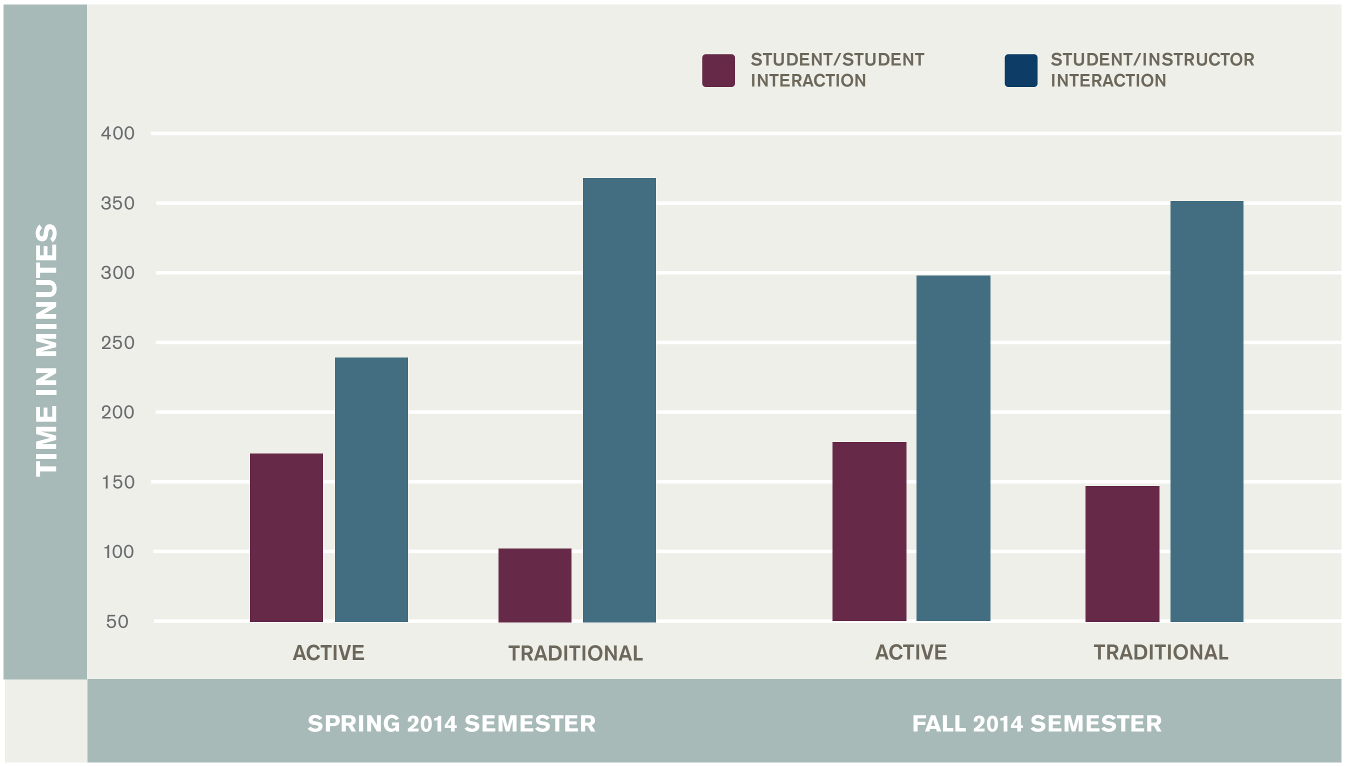


Figure 3. *Student/Student and Student/Instructor Interactions in Active and Traditional Classrooms*

With both instructors, students In the active learning classroom engaged with each other more while "passive learning" such as engagement with the instructor's lecture or with class material decreases. The opposite is seen in the traditional classroom. This observation holds true across two different instructors with somewhat different instructional styles and four different student populations over two semesters.

Student Disengagement

Using the raw averages, we observed that students in the active classroom were more disengaged than those in the traditional classroom. On the average, students in the active classroom were disengaged 89.0 seconds per incident compared to those in the traditional classroom who were disengaged 63.5 seconds. This is a caution to instructors that with more opportunities to digitally connect, students are more often not on task.

Student/Built Environment Interaction

Furthermore, using the raw averages again, we observed that students in the active learning classroom interacted with the built environment more than those in the traditional classroom. These behaviors included students' use of white boards, projectors, technology devices, and furniture. Students in the active classroom interacted with the built environment three times more than those in the traditional classroom. This suggests the furniture, white boards, technology and equipment have a strong positive effect on student and instructor behavior.

Student Perceptions– Affective Domain

For analysis and interpretation, the 14 scales in the Architecture Learning Environment Survey (ABLES) were organized into four groups. Analyzing the results of grouping the scales reveals a more nuanced understanding of students' perceptions of the architecture-learning environment.

The first group consists of two scales—Physical Space and Material Environment—that address 'classroom design'. In the active learning classrooms (n=19; 95% response rate), students perceived both of these elements more positively than their peers in the traditional classrooms (n=22; 76% response rate) (see Figure 4). The average item mean (on a 5-point scale) for Physical Space that assesses the extent to which classroom space promotes effective learning, was 3.80 in the traditional classroom while the average item mean in the active learning classroom was 4.39, a difference of 0.59. However, the difference between students' perceptions of Material Environment that assesses the extent to which classroom equipment and materials were adequate was not as great between the traditional and active learning classrooms (0.14) as it was for Physical Space.

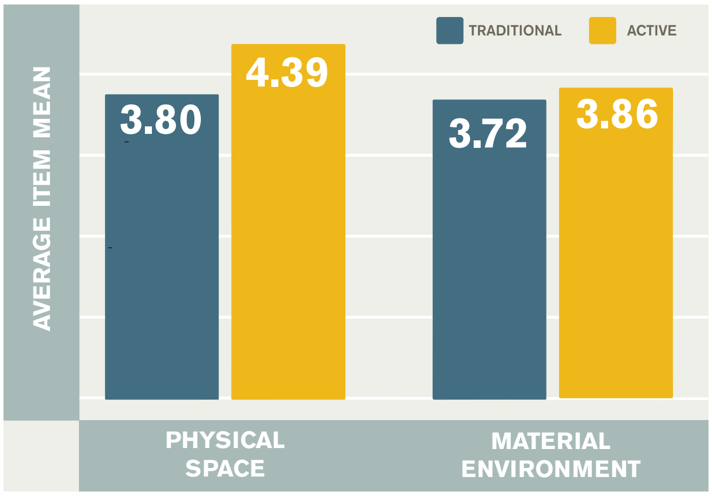


Figure 4. *Student Perceptions of the Physical Space Showing Average Item Means for Two Scales From the Architecture Learning Environment Survey That Address Classroom Design (n=22 in traditional class; n=19 in active learning class). Response Options Were 1-Almost Never, 2-Seldom, 3-Sometimes, 4-Often, 5-Almost Always.*

Figure 5 shows the results comparing students' perceptions in the second grouping consisting of six scales that address 'instruction'. The results were mixed. Specifically, students' perceptions of two elements—Innovation and Instructor Support—were more positive in the active learning classroom compared to the traditional classroom. Innovation revealed the greatest positive difference (0.38) in this group. For the remaining four scales—Personal Relevance, Investigation, Open-Endedness, and Equity—students' perceptions were more positive in the traditional classroom. Differences range from 0.11 to 0.42.

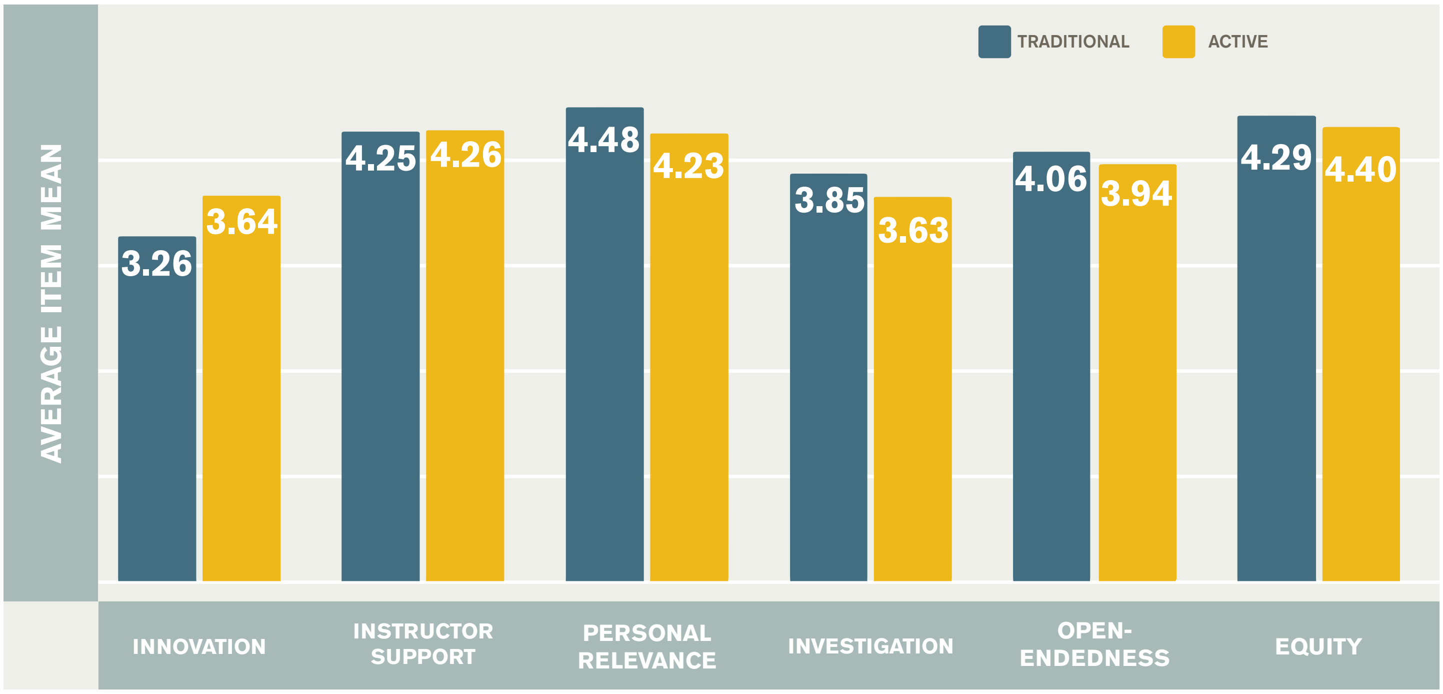


Figure 5. *Student Perceptions of Instruction Showing Average Item Means for Six Scales From the Architecture Learning Environment Survey That Address Instruction (n=22 in traditional class; n=19 in active learning class). Response Options Were 1-Almost Never, 2-Seldom, 3-Sometimes, 4-Often, 5-Almost Always.*

Figure 6 shows the results comparing the active learning classroom versus the traditional classroom with regard to the third group that addresses 'student behaviors'. This group consists of Student Cohesiveness, Cooperation, Involvement, and Task Orientation. Students' perceptions were more positive in the traditional classroom across all four scales. However, differences were small and range from 0.01 to 0.22.

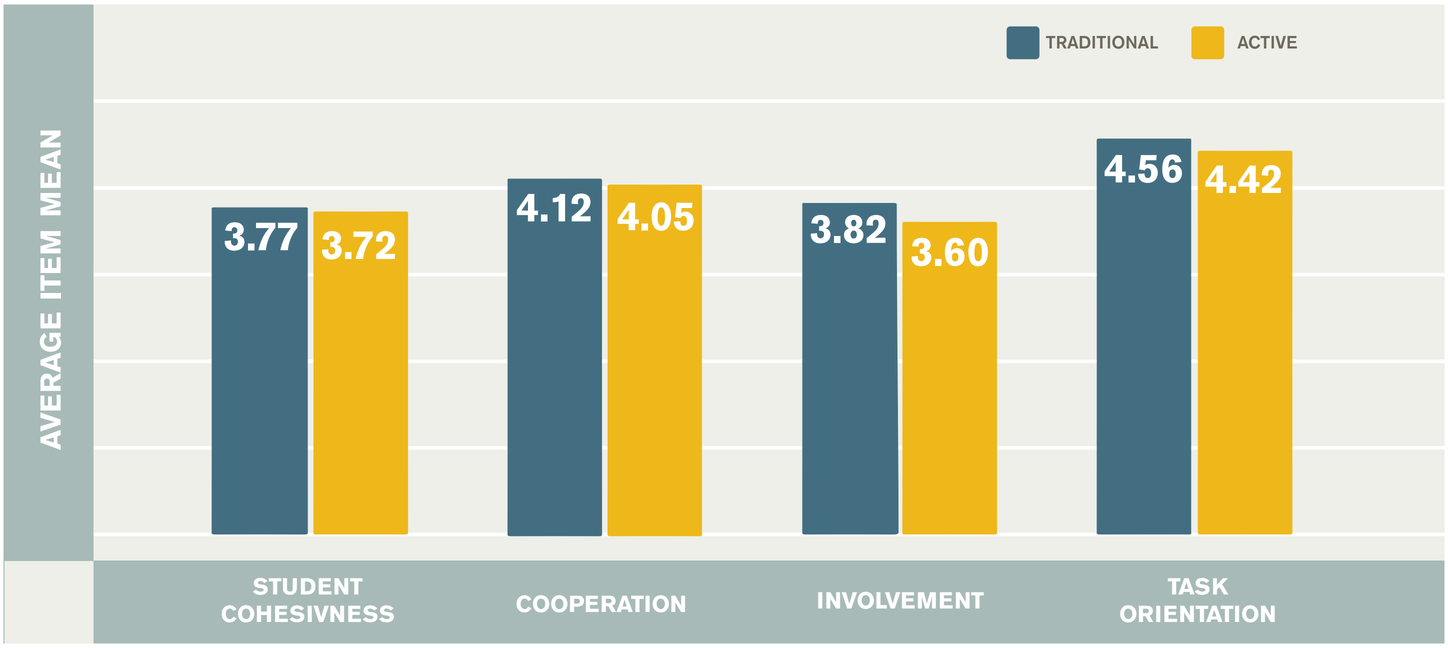


Figure 6. *Perceptions of Student Behaviors Showing Average Item Means for Four Scales From the Architecture Learning Environment Survey That Address Student Behaviors (n=22 in traditional class; n=19 in active learning class). Response Options Were 1-Almost Never, 2-Seldom, 3-Sometimes, 4-Often, 5-Almost Always.*

While the first three groups deal with students' perceptions of their learning environment, the fourth group reveals students' self-report of two 'affective factors' (see Figure 7). For both Attitude and Academic Self-Efficacy, students' self-ratings were higher in the traditional classroom compared to the active learning classroom. Differences were 0.24 for Attitude and 0.11 for Academic Self-Efficacy.

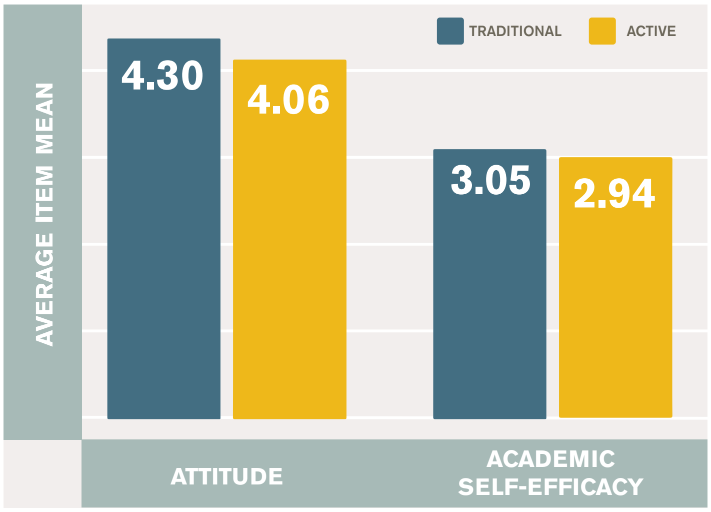


Figure 7. *Student Attitudes and Academic Self-Efficacy Showing Average Item Mean for Two Scales From the Architecture Learning Environment Survey That Address the Affective Domain (n=22 in traditional class; n=19 in active learning class). Response Options Were 1-Strongly Disagree, 2-Disagree, 3-Neither Agree nor Disagree, 4-Agree, 5-Strongly Agree.*

Of the four groups of scales in the Architecture Learning Environment Survey, students' perceptions of 'classroom design' consisting of Physical Space and Material Environment suggest the most significant differences in favor of the active learning classroom. This seems logical considering that the active learning classroom was purposively-designed to promote active learning with its placement of round tables and technology equipment, moveable chairs, whiteboards on the walls, and no front-of-the-room podium for the instructor. Also noteworthy is the fact that we created five new items for the 'classroom design' group as we felt this aspect of the learning environment was untapped (or unassessed) in previous instruments. With these positive results in favor of the active learning classroom, we are encouraged to see that students do in fact notice a difference in the Physical Space and Material Environment in the two classroom settings. In the 'instruction' group of scales, there also appears to be a significant positive difference in favor of the active learning classroom for the scale of Innovation. Students perceived the active learning classroom as more innovative because the instructor used new and different ways of teaching and created innovative activities for students, new ideas were tried out, the seating arrangement changed every week, and innovative technology was used. Also in this group, Instructor Support was perceived as essentially the same in both the traditional and active learning classrooms. This finding is in fact desirable because the same instructor taught classes in both rooms, and we did not want him to modify his instruction depending on the space.

For the remaining 10 scales, students' perceptions were more positive in the traditional classroom but differences were small. A larger sample size in both types of classrooms would be necessary to enable us to confidently make any conclusions regarding these particular aspects of the learning environment.

STUDENT INTERVIEWS

To understand the effectiveness of active learning spaces on the individual student we asked a series of questions in one-on-one interviews.

What type of learner are you in a typical classroom?

Hao, is a student from Vietnam and was in the active learning classroom during the first semester. *"I am very shy, less answer the question, very formal, when I know that the right answer, 90% the right answer, I will answer it, otherwise I will keep it to myself and maybe ask the teacher later."*

Marianne is fourth year student who is recently from Brazil. *"I wouldn't dare to lift my hand to answer a question. I think it is because of my language; because of the issue of my language. It is not my native language. So I have this boundary. I wouldn't dare to talk in front of a lot of people."*

Ian is an African American third year student from Baltimore who excelled at one of the best city public high schools. *"Maybe in general professors speak as if I am already a professional and I am going to understand his perspective. And that's not where the students are going to understand from."*

Ayman is the son of Persian parents whose early education happened in Dubai, but attended a suburban Maryland high school. *"In my culture as a whole, the Middle-Eastern culture, education is taken really seriously. They don't play around. " I am the kind of guy who sits in the front of the class because I want the professor to know that's the kind of student I am."*

Brian is a white third year student from rural Pennsylvania; he waited five years after high school to attend college. *"I entered the program as a mature undergraduate…being a little more seasoned in life, I maybe tend to have a better sense of focus."*

How did you feel in the active learning classroom?

Brian found a setting that encourages more student engagement. *"I think it creates a place where you are comfortable enough to discuss. I think there is kind of a relaxed environment that helps you feel comfortable to speak up and discuss the topics you are studying."*

Marianne was able to practice her language skills. *"I felt comfortable … I don't know… to be myself here and talk with the people that were at my table. I got used to talk more and express myself more."*

Ayman appreciates the cooperative rather than competitive culture of the class. *"It's nice to be able to all rely on one another equally rather than have strong kids in the class and the kids that… you know… sit in the back."*

Hao discovered a setting where risk taking was rewarded. *"I guess in like a really formal environment that you don't want to answer the question and you don't want people laughing at the wrong answer; and you don't want to get the wrong answer as well. But when there's like a normal conversation… if it's wrong it's wrong; I can learn from them."*

What about the space encouraged you to interact?

Brian saw value in public construction and sharing of knowledge. *"If every group has a white board it's easy to convey those ideas. Then you can see what everyone else is writing. I think it encourages discussion a little more."*

Ian realized the round tables promote not only speaking but listening. *"I think if you are next to two or three other people it forces you to talk. And you're facing each other so I think it forces you to hear somebody else's opinion."*

How did the space improve the learning?

Marianne became part of a social community of learners. *"But when you have to interact and when you have to talk about it and when have to really make yourself part of something… then you learn."*

Ian likes the ease of learning from peers. *"I think in a lot of classes you learn more from students than you do from teachers sometimes."*

Ayman took ownership of his own learning. *"I fit right in and the learning, the creative thinking and the collaboration started almost immediately. So… I was responsible for my learning."*

Instructor Interview

The instructor confirmed the active learning classroom was far better at creating a comfortable environment for both the students and the instructor. Interestingly, the physical space seemed to change how he was perceived in each room. Although the pedagogy was the same in both classrooms, students in the traditional classroom raised their hand to ask a question and relied on the instructor much more for guidance, while the students in the active classroom relied far more on each other for solutions. Student diversity created both opportunities and challenges. Students felt freer to vocalize multiple perspectives, which created richer discussions and challenged stereotypes. But a diverse class also means a vast variance of preparedness. These students come from a variety of cultures and education backgrounds. Many balance school and work and have less time outside of class to prepare. The active learning class helped the less prepared student by allowing them to witness how colleagues at their table construct their thoughts and by providing multiple peer instructors to help explain concepts.

LEARNING OUTCOMES – COGNITIVE DOMAIN

Grades Analysis

The HCM/Morgan State Study builds on the University of Minnesota research, which used grades as a measure of learning outcomes. The Minnesota study compared the average class grade with the average class ACT score to understand how students perform compared to the expectation of their performance. The subjects of this study were all upper classmen, with existing college Grade Point Averages, (GPA). We will use the average student GPA as the predictor of the learning outcome. Therefore we averaged student grades and compared them to the average GPA for each class as one measure of the learning outcome.

Table 5. *Grades Analysis For Students in the Active and Traditional Classrooms*

CLASSROOM TYPE	CLASS GRADE	OVERALL GPA	RATIO (CLASS GRADE/ OVERALL GPA)
Active Learning	2.95	2.84	1.04
Traditional	2.33	2.70	0.86

As seen in Table 5, the students in the active learning classroom out-performed their expected outcome, (average class grade compared to average class GPA). The students in the traditional classroom surprisingly underperformed when compared to their expected outcome. Recall that the project controls included the same instructor, pedagogy, course content, time of day, etc. **Given these project controls, the results indicate that the physical space of the active learning classroom alone has a strong positive effect on student learning outcomes.**

The Instructor's Perspective: The Four C's

ARCH 305, "Design and Human Behavior" at Morgan was structured to provide students as many opportunities as possible to build strengths in the Four C's of 21st Century skills– Critical Thinking, Collaboration, Creativity, and Communication. The Four C's, as developed by the National Education Association, have become over the last decade a national movement to move beyond strictly content based coursework towards learning experiences that not only deliver content, but prepare students to be successful in an ever changing global society.
For each of the Four C's, the instructor defined specific learning goals to assess the quality of the class, and student achievement.

Critical Thinking

- The ability to engage in reasoned discussion as a way of building and sharing understanding of the course concepts

Collaboration

- Develop an understanding of one's own strengths by working with others
- Learn from listening and speaking
- Learn how to manage time, and create exponentially more.

Creativity

- Apply concepts in class to issues facing Baltimore
- Build Intellectual capacity to see an issue from multiple sides and creatively respond

Communication

- Public Speaking (Extemporaneous and scripted)
- Persuade others in small groups
- Visually communicate complex ideas and make persuasive arguments in presentations

It is much easier to facilitate active learning practices in a room designed for it

The biases of the traditional learning classroom became abundantly clear when trying to group students. In the rows of computer stations and desks in the traditional classroom, face to face communication between students was difficult. The instructor could not join a student group seated at the table as collaborator; rather he had to roam the space between rows awkwardly standing, peering down at student groups as an instructor at best, a judge at worst. The physicality of the instructor's position and role had a significant impact on student behavior. Collaborative work in the traditional classroom tended to be more quiet and discreet, almost as if the groups did not want the instructor to hear thoughts in progress, or questions being sorted through. However, in the active classroom, the moment the instructor joined the group in a seated position around the round table, not only was he able to observe the discussion without change in tone or intensity, but he was often able to participate and guide it as a fellow thinker.

Students in the active learning environment were able to demonstrate competency in the 4Cs more frequently and with greater ease than in the traditional learning environment

The National Training Laboratory found that while only 5% of the information in a lecture is retained on average by students, when students teach other, 80% of the information is retained. This staggering increase in the information retained suggests that even the retention of content is enhanced when students have the opportunity to actively apply what they are learning, in this case, by teaching others.

As an HBI located in a major metropolis, the student body of Morgan State is quite diverse by any standard. This diversity was a considerable strength for the class in collaborative activities. Students were able to draw upon their diverse experiences, backgrounds, and perspectives on the material, and expand each other's understanding of the material at hand. Moreover, students with stronger reading comprehension, were able to explain new material to others in ways that were relevant, approachable, and perhaps more impactful than the instructor. Finally, since every student was invited to draw on their unique perspective, each student was able to "teach" another, and come to a greater understanding of their own perspective through trying to explain it.

Round tables allowed students to test ideas and build critical thinking skills in small group discussions before sharing with the larger group

The round tables allowed students to communicate better. The intimacy of being able to see each other face to face, to be able to use a lower volume of voice, and sense a feeling of community seemed to give students the confidence to process more out loud, and sharpen their thinking through discussion. This was particularly valuable for international students building English skills. They may have been too shy to raise their hand in large lecture hall in response to a question, but were willing to try their rhetorical skills in the more intimate setting of a 4 foot diameter round table.

Flat Panel Displays Focused Digital Collaboration

The multiple large scale digital displays provided a wide range of new learning opportunities. Students in a group could now collaborate on a single presentation in real time viewed on the large scale display. The instructor could guide the entire class to any one of the displays to view work in progress, and ask probing questions about the concepts being developed, and this in turn helped develop Critical Thinking.

The instructor also noticed that students in the active learning class tended to look up more to see the room, and the presentations emerging on the screens. The instructor suspects that seeing many different responses to guiding questions, or activity prompts broadened the thinking of students, and helped create the "buzz" of energy that made the classes so fun.

Midterm and Final Papers in Active Learning Class tended to be more creative and had greater depth than Traditional Learning Class

Students in the active learning class were more in command of concepts, and therefore could be more creative in applying them in the midterm and final papers, which had significant impact on their grade. The midterm and final papers, which challenged students to apply the range of concepts learned in the course, illustrated the degree to which students understood the material. On average and at the extremes of success and minimal competency, those in the active learning class demonstrated more understanding of the material by applying it more creatively.

Lessons Learned

Although the physical environment of the active learning class created many more opportunities for developing the 21st Century skills of the Four C's, the instructor did learn many lessons about implementing active learning pedagogy that transcend space.

1) At least 90 minutes are needed to seriously get in to an active learning session. Critical thinking, Collaboration, and Creativity take time. Meaningful Communication requires listening, and thoughtful response, which both take time. To cycle through an active learning exercise, particularly with a meaningful report out, and discussion, 90 minutes is an absolute minimum. At 75 minutes, the best conversations were often being cut off.

2) A critical mass of students is needed to create the energy and range of ideas necessary to make active learning meaningful. When attendance is low or class size small, groups lose their energy.

3) Active Learning classes would be even more effective if students on average had stronger critical thinking and writing skills and experience with active learning before beginning the course. It is difficult to expose students to the Four C's and new content in one 16 week semester. As more classes take on this approach and students become more acculturated to these ways of thinking, each active learning class will benefit.

SUMMARY OF FINDINGS

This pilot study used a small student sample, but findings confirm those of previous studies for this unique group, and provide valuable new insights into the effectiveness of the active learning classroom for a diverse student population.

Social Domain

- The active learning classroom space alone provides a positive effect on student and instructor behavior by promoting more student-to-student interaction and less student to instructor interaction, correlating with more social, engaged, active and robust learning.

- Students interacted with the built environment features, i.e. whiteboard, furniture and technology three times more in the active learning classroom than in the traditional classroom.
- Students were more disengaged in the active learning classroom, i.e. more devices = more distractions

■ **Affective Domain**

- Students had more positive perceptions toward the physical space, material environment, and innovation in the active learning space.
- Inhibitions that a diverse student class experiences in a lecture classroom are mitigated by the comfortable, cooperative, peer-supported, technology-rich environment of the active learning classroom.
- Although pedagogy was identical, the instructor acted as a guide and peer in the active learning classroom and as the teacher and authority figure in the traditional classroom.

■ **Cognitive Domain**

- Students develop superior 21st century skills including communication, collaboration, creativity and critical thinking in the active learning classroom.
- Learning outcomes are enhanced for a diverse class in the active learning classroom.

CONCLUSION

Precedent studies have shown that active learning classroom settings contribute to superior learning outcomes, by affording students a social context to construct knowledge among a group of peers. We wondered what would happen when ethnic diversity changes the demography of the peers. Would a diverse group still work together as successfully as the homogenous groups in previous studies? The results of our pilot project are clear. A diverse student group has produced far improved learning outcomes in the active learning classroom when compared to the traditional classroom. In fact, the study strongly suggests an active, engaged, peer-to-peer learning setting is almost vital for a diverse group of students who come with unique inhibitions to traditional classroom engagement. We acknowledge factors that discourage class engagement occur in the traditional majority of students. But considering language differences, cultural background, and the variance of preparedness of diverse students, this group experiences far more inhibitions to typical classroom engagement than their majority peers. In this study, the students' social behavior, their own perceptions, and cognitive measures all indicate the physical design of active learning classrooms contributes in mitigating their inhibitions, promoting engagement, and producing enhanced learning outcomes.

RECOMMENDATIONS

We encourage architects and all learning space designers to use this report as evidence that the diverse student class of the future will produce superior learning outcomes in active learning classrooms. We encourage facility design decision makers at HBI's, community colleges and all universities that anticipate a future diverse student body, to embrace these as the standard learning spaces.

Next steps should include research of diverse students and collaborative learning spaces on a larger scale to achieve more conclusive results. Other interesting variables may include comparing outcomes from students at private versus public schools, community colleges, varying course content, altering the mix of ethnicity to reflect a specific region, gender, age, economic background, and student preparedness.

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References

Alberts, B. A. (2005). Wakeup Call for Science Faculty. Cell 123, p.739-741.

Barnette, J. (2000). Effects of stem and Likert response option reversals on survey internal consistency: If you feel the need, there is a better alternative to using those negatively worded stems. Educational and Psychological Measurement, 60, 361-370.

Baroncelli L, Braschi C, Spolidoro M, Begenisic T, Sale A, Maffei L. Nurturing brain plasticity: Impact of environmental enrichment. Cell death and differentiation.17 (7):1092-103.

Beichner, R, Burniston, E., Dail, P., Felder, R., Gastineau, J., Gjertsen, M., Risley, J. (1999). Case study of thephysics component of an integrated curriculum. American Journal of Physics, Suppl 67 (7), 16-24.

Beichner, Robert J., (2008). A Student-Centered Active Learning Environment for Undergraduate Programs, pages 1-13.

Bleske-Rechek, A. (2002). Obedience, conformity, and social roles: Active learning in a large introductory psychology class. Teaching of Psychology, 28, 260-262.

Blumberg, P. (2009). Developing learner-centered teaching: A practical guide for faculty. San Francisco, CA: Jossey-Bass.

Brooks, D. Christopher, (2010). Space Matters: The impact of formal learning environments on student learning. British Journal of Educational Technology, 1-8.

Brooks, D. Christopher, (2012). Space and Consequences: The Impact of Different Formal Learning Spaces on Instructor and Student

Behavior. Journal of Learning Spaces, 1, (2).

Bryck RL, Fisher PA. Training the brain: practical applications of neural plasticity from the intersection of cognitive neuroscience, developmental psychology, and prevention science. The American psychologist. 2012; 67(2):87-100.

Burgess N, Maguire EA, O'Keefe J. The human hippocampus and spatial and episodic memory. Neuron. 2002; 35(4):625-41.

Campbell FA, Pungello EP, Burchinal M, Kainz K, Pan Y, Wasik BH, et al. Adult outcomes as a function of an early childhood educational program: an Abecedarian Project follow-up. Developmental psychology. 2012; 48(4):1033-43.

Clement N, D., Lovat T. Neuroscience and Education: Issues and Challenges for Curriculum. Curriculum Inquiry. 2012; 42(4):534-57.

Cleveland (2009). Engaging spaces: An investigation into middle school educational opportunities provided by innovative built environments: A new approach to understanding the relationship between learning and space. The International Journal of Learning, 16, 385-397.

Cleveland, B., & Fisher, K. (2014). The evaluation of physical learning environments: A critical review of the literature. Learning Environments Research: An International Research, 17, 1-28.

Cotner, S., Loper, J., Walker, J., Brooks, D. (2013). "It's not you, it's the room"—Are the high-tech, active learning classrooms worth it? Journal of College Science Teaching, 42, 82-88.

Diamond MC. Response of the brain to enrichment. An Acad Bras Cienc. 2001; 73(2):211-20.

Dori, Yehudit Judy, Belcher, J., Bessette, M., Danziger, M., McKinney, A., Hult, E., (2003). Technology for Active Learning. Materials Today, (December), 44-49.

Dori, Yehudit Judy, Belcher, John, (2005). How Does Technology-Enabled Active Learning Affect Undergraduate Students' Understanding of Electromagnetism Concepts? The Journal of Learning Sciences, 14(2), 243-279.

Eberhard JP. Applying neuroscience to architecture. Neuron. 2009; 62(6):753-6.

Fraser, B. (2001). Twenty thousand hours. Learning Environments Research: An International Journal, 4, 1-5.

Fraser, B. (1981). Test of science-related attitudes (TOSRA). Melbourne, Australia:Australian Council for Educational Research.

Fraser, B., Fisher, D., & McRobbie, C. (1996, April). Development, validation, and use of personal and class forms of a new classroom environment instrument. Paper presented at the annual meeting of the American Educational Research Association, New York.

Fraser, B., Giddings, G., & McRobbie, C. (1995). Evolution and validation of a personal form of an instrument for assessing science laboratory classroom environments. Journal of Research in Science Teaching, 32, 399-422.

Fraser, B., Treagust, D., & Dennis, N. (1986). Development of an instrument for assessing classroom psychosocial environment at universities and colleges. Studies in Higher Education, 11, 43-54.

Freeman, S., O'Connor, J., Park, M., Cunningham, D., Hurley, D., Haak, C., Dirks, C., & Wenderoth, M. (2007). Prescribed active learning increases performance in introductory biology. CBE—Life Sciences Education, 6, 132-139.

Frey, William H. (2012). Census Projects New "Majority Minority" Tipping Points. Brookings Institution, December 13, 2012, Number 60 of 64.

Gage FH, editor Neuroscience and Architecture: Theme Presentation. AIA National Convention and Expo; 2003; San Diego, CA.

Gensler. (2012). Changing Course: Connecting Campus Design to a New Kind of Student. Design and Performance Report.

Gislason, N. (2010). Architectural design and the learning environment: A framework for school design research. Learning Environments Research: An International Research, 13, 127-145.

Hake, R.R. (1998). "Interactive engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses." American Journal of Physics 66(1): 64.

Handelsman, J. Ebert-May, D., Beichner, R., Bruns, P., Chang, A. DeHaan, R. Gentile, J. Lauffer, S., Stewart, J., Tilghman, S. M., Wood, W. B. (2004). Scientific Teaching. Science 304(5670) p. 521-522.

Hannan AJ. Environmental enrichment and brain repair: harnessing the therapeutic effects of cognitive stimulation and physical activity to enhance experience-dependent plasticity. Neuropathol Appl Neurobiol. 2014; 40(1):13-25.

Hebb DO. The organization of behavior: A neurophysiological theory. N.Y.: John Wiley & sons; 1949.

Hohmann CF, Hodges A, Beard N, Aneni J. Effects of brief stress exposure during early postnatal development in balb/CByJ mice: I. Behavioral characterization. Dev Psychobiol. 2013; 55(3):283-93.

Jinks, J., & Morgan, V. (1999). Children's perceived academic self-efficacy: An inventory scale. Clearing House, 72, 224-230.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1991). Active Learning: Cooperation in the College Classroom. Edina, MN: Interaction Book Company.

Kemperman G, Gage FH. Experience dependent regulation of adult hippocampal neurogenesis: effects of long-term stimulation and stimulus withdrawal. Hippocampus. 1999; 9(3):321-32.

Knight, J., & Wood, W. (2005). Teaching more by lecturing less. CBE—Life Sciences Education, 4, 298-310.

Lage, Maureen J., Glenn J. Platt and Michael Treglia. (2000). "Inverting the Classroom: A gateway to creating and inclusive learning environment". Journal of Economic Education, 31(1), p. 30-43.

Merzenich MM, Sameshima K. Cortical plasticity and memory. Current opinion in neurobiology. 1993; 3(2):187-96.

Meyer, R. (2013). The post-lecture classroom: How will students fare? www.theatlantic.com/technology/print/2013/09/the-post-lecture-classroom-how-will-students-fare/279663/

Mohammed AH, Zhu SW, Darmopil S, Hjerling-Leffler J, Ernfors P, Winblad B, et al. Environmental enrichment and the brain. Prog Brain Res. 2002; 138:109-33.

O'Hare, William. (2011). The Changing Child Population of the United States: Analysis of Data from the 2010 Census. Annie E. Casey Foundation KIDS COUNT Working Paper, November 2011, 1-25.

Nogaj, L. (2013). Using active learning in a studio classroom to teach molecular biology. Journal of College Science Teaching, 42, 50-55.

Pascual-Leone A, Amedi A, Fregni F, Merabet LB. The plastic human brain cortex. Annual review of neuroscience. 2005; 28:377-401
Prince, M. (2004). Does active learning work? A review of the research. Journal of Engineering Education, 93, 223-231.

Ramey CT, Ramey SL. Early intervention and early experience. The American psychologist. 1998; 53(2):109-20.

Rosenzweig MR, Bennet EL. Psychobiology of plasticity: effects of training and experience on brain and behavior. Behav Brain Res. 1996;78:57-65.

Sale A, Hannan AJ, Maffei L, Guzzetta A. Noninvasive strategies to optimize brain plasticity: from basic research to clinical perspectives. Neural plasticity. 2013;2013:863970.

Schaaf RC, Miller LJ. Occupational therapy using a sensory integrative approach for children with developmental disabilities. Mental retardation and developmental disabilities research reviews. 2005;11(2):143-8.

Scott-Webber, Lennie, Strickland, Aileen, Kapitula, Laura Ring, (2013). Built Environments Impact Behaviors, Results of an Active Learning Post-Occupancy Evaluation. Planning for Higher Education Journal, V42N1, October-December, 1-12.

Smith TJ. The ergonomics of learning: educational design and learning performance. Ergonomics. 2007;50(10):1530-46.

Taylor, P., Fraser, B., & Fisher, D. (1997). Monitoring constructivist classroom learning environments. International Journal of Educational Research, 27, 293-302.

Van Praag, H., G. Kempermann, and F.H. Gage,(2000) Neural consequences of environmental enrichment. Nat Rev Neurosci,. 1(3): p. 191-8.

Voss JL, Gonsalves BD, Federmeier KD, Tranel D, Cohen NJ. Hippocampal brain-network coordination during volitional exploratory behavior enhances learning. Nature neuroscience. 2011;14(1):115-20.

Walker, J.D., Brooks, Christopher, Baepler, Paul, (2011). Pedagogy and Space: Empirical Research on New Learning Environments. EDUCAUSE Quarterly, 34(4).

Weimer, M. (2002). Learner-centered teaching: Five key changes to practice. San Francisco, CA: Jossey Bass.

Welsh, A. (2012). Exploring undergraduates' perceptions of the use of active learning techniques in science lectures. Journal of College Science Teaching, 42, 80-87.

Whiteside, Aimee L., D. Christopher Brooks, and J.D. Walker. Making the Case for Space: Three Years of Empirical Research on Learning Environments.

Woollett K, Maguire EA. Acquiring "the Knowledge" of London's layout drives structural brain changes. Current biology : CB. 2011;21(24):2109-14.

Yoder, J., & Hochevar, C. (2005). Encouraging active learning can improve students' performance on examinations. Teaching of Psychology, 32, 91-95.