IN PLANNING SCIENCE LABS: BEWARE OF UNINTENDED CONSEQUENCES

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ABSTRACT

The role of designed classrooms and the use of space as components of education have not received a great deal of attention since open classrooms were studied in the early to mid-1970's. Instead, researchers have focused on curriculum. "One thing we have learned from examining the history of curriculum in the 20th century is that curriculum reform has had remarkably little effect on the character of teaching and learning in American classrooms" (Larabee, 2000, p. 148). Required new patterns of instruction and testing forms point to the need to reconsider spaces designed for science learning. Better use of existing classroom space can provide a nurturing, learning environment (Simplicio, 1999). Duncanson (2001) found that classroom space has a high positive correlation to hands-on science skills (r = .910, p = .032). Rooms with larger amounts of oor space per student promoted higher attainment of student outcomes. In addition, researchers in Kentucky found that school climate as a correlate of student achievement was more important than curriculum, assessment, and professional development. Successful schools had a learning environment that respected the needs of students (Browne-Ferrigno, et al., 2006). These results point to the fact that the center for school improvement resides in classrooms.

INTRODUCTION

Prior to 1990, science laboratories for chemistry and physics commonly used xed lab tables that doubled as desks for four to eight students. Earth science and biology classrooms tended to have tables for two students arranged in the traditional pattern of rows with narrow aisles. Both formats supported teacher directed activities in a teacher-centered science classroom. New buildings sometimes incorporated a seating area in front of a separate laboratory area in the back of the room. A few schools used separate rooms for classroom and laboratory areas, but this arrangement hindered class-lab instruction continuity. In the 1990's, architects began adding more counter space to the outside edges of classrooms and increased storage spaces. This created larger work spaces for students in support of national curriculum projects [e.g. Biological Sciences Curriculum Study (BSCS), and the Earth Science Curriculum Project (ESCP)] that involved students in a wider variety of hands-on activities. Laboratory facilities designed and built since 2000 tended to feature widely separated work areas on the edges of the room. The spacious classrooms and large work areas are meant to parallel "real world" conditions, where scientists have separated work spaces. This horizontal layout was intended to promote a student-centered learning approach emphasizing analytical or applied questioning by teachers (Betoret & Artiga, 2004).

The physical condition of many science labs is also an area of concern. The American Society of Civil Engineers (ASCE) reported that while school enrollment was increasing, funding for renovating older classrooms was decreasing. The available money is below what is needed to bring schools to good overall conditions. The ASCE assigned a grade of 'D' to the physical quality of American schools (ASCE, 2007). The size and design of science facilities have had unintended negative consequences for instruction, safety, and personalization. Science labs must change to accommodate new testing and instruction.

INSTRUCTIONAL SPACE

Teachers and the physical environment are two important "tools" that can bring about new outcomes. Proxemics--the study of space and the way people use it--is important in designing classrooms. "No matter what happens in the world of human beings, it happens in a spatial setting, and the design of that setting has a deep and persisting in uence on the people in that setting" (Hall, 1966, p. xi). Classrooms often support teaching, ignore students' interests.

Unintentionally and non-verbally teachers expose their educational philosophy in the ways they use space (Sommer, 1977). People react to space between themselves and other human beings. Hall (1966) created a scheme that divided space for human interactions into four regions: intimate, personal, social, and public. The size of each territory in uences eye contact, the level of voice used, and the nature of the conversation taking place. “The boundaries of the territories remain reasonably constant” (Hall, 1966, p. 102-103). When people are within 1 inch of each other (intimate range), they can whisper, communicating personal information not meant to be repeated. Personal space extends from 1.5 feet to 4 feet. At this distance, about an arm’s length, people can communicate in a soft voice while discussing personal subject matters. A normal speaking level can be used for a social distance of 4 feet--8 feet. Between 8 feet and 12 feet a speaker must raise his or her voice level. “At this distant phase, the voice is noticeably louder than for the close phase, and it can usually be heard easily in an adjoining room if the door is left open” (Hall, 1966, p. 122). Public space begins at 12 feet from the speaker. The speaker’s voice must be loud but not shouting.

Table 1:
*Required Shifts in Voice Levels Driven by Distance Between Communicators**

Communication Type	Distance	Level/Topics (verbal and nonverbal)
Intimate	up to 1 ft.	whisper; con dential information
Personal	1.5 ft. – 4 ft.	soft voice, personal matters
Social – near	5 ft. – 8 ft.	full voice; information of a non-personal nature
Social – far	8 ft – 12 ft.	raised voice; public information
Public	over 12 ft.	loud voice; speaking to a group

Adapted from Hall, 1959

Note: The exact distances may have varied somewhat since 1966, but the four categories are still relevant. Cultures may differ in their use of space and eye contact.

Multiple hidden non-verbal dimensions are part of culture. How teachers use space is related to their use of time. When classrooms have narrow pathways, little space per student, and lack useable work space, teachers are forced to teach in constrained space and emphasize rote learning activities. Communication is narrow and one-way with the teacher doing the talking. Larger classrooms offer more space per student, broad pathways, and open areas where students can self-select comfortable work areas (Hall, 1976). Spacious environments support inquiry learning where students engage in different activities at the same time. Teachers can coach students in small groups “as they become deeply involved in the knowledge and skills needed to complete the activity” (Duncanson, 2003b, p. 3).

“It is dif cult, if not impossible, to separate instructional activity from the physical environmental setting within which it occurs” (Lackney & Jacobs, 2002, p. 1). The physical environment may impede the effectiveness of instruction. When classrooms remain unchanged despite changes in teaching strategies a mismatch occurs. “As a result, the program and the setting in which that program takes place are often in con ict with each other hindering both teaching and learning” (Lackney & Jacobs, 2002, p. 4). Increasing student space has been shown to improve student achievement signi cantly. “Collectively, the hands-on skills of classifying, manipulating materials, measuring, recording data, and using non-standard units of measurement, and the thinking skill of making predictions show a high positive correlation to classroom space” ($r = .881$, $p = .048$) (Duncanson, 2003, p. 110).

Overly large classrooms may lead to multiple problems for the teacher. In newly designed classrooms, continuously speaking across large distances has created medical problems for teachers. “Teachers are 32 times more likely than other professionals to have voice disorders” (Wagner, 2004). At distances over 8 feet a raised teacher voice may discourage students from asking higher-order thinking questions. The non-verbal message of space should encourage on-subject conversation (Richards, 2006).

Research in 16 science labs has shown that in a class setting with the teacher standing near the chalk/whiteboard, that some students were 25 feet or more away from the instructor (Duncanson & Achilles, 2007). The distance was even greater when students are using lab stations on the perimeter of the room. Long distances require the teacher to speak continually at an elevated level. Large distances create line-of-sight (LOS) problems for the teacher enabling some students to escape the teacher's field of vision. Individual monitoring of students becomes difficult.

Impersonalization can lead to misuse of equipment and students who are off-task (Connolly, 2007). Few teachers know how to create learning environments that address the needs of today's curriculum, testing forms, and student preferences. Teachers report that they received no formal training on how to plan space use and room arranging; many teachers learn about organization patterns by looking into the classrooms of other teachers (Weaver, 1998). "A new teacher-training model must prepare teachers to become environmentally competent 'placemakers' for student instruction and learning" (Lackney & Jacobs, 2002, p. 3). This is not as easy as it sounds. "A major challenge in professional development is helping teachers unlearn the beliefs, values, assumptions and cultures underlying schools' standard operating practices" (Dede, 2004, p. 16). Allocation of space is a major ingredient for improving teaching and learning (ASCD, 2007). The National Science Teachers Association (NSTA) said that science labs must be remodeled to promote safe habits and procedures. Laboratory teaching needs to support inquiry-based learning that is part of daily instruction and help students learn in a collaborative setting. Science activities should be conducted in a well-equipped, safe, laboratory space (NSTA, 2007).

SAFETY

Students are asked to 'do' science rather than just read about it in a book. "If students themselves participate in scientific investigations that progressively approximate good science, then the picture they come away with will likely be reasonably accurate. But that will likely require recasting typical school laboratory work" (AAAS, 1993, p. 9). Hands-on laboratory experiences help students make sense of the environment, and are related to student outcomes (NRC, 2005). Teachers are expected to use laboratory activities as a teaching technique (NSTA, 1985).

In this new teaching environment, teachers are also expected to meet standards of the EPA, OSHA, and/or the appropriate state and local regulatory agencies (NSTA, 2000), but few teachers have received formal training in laboratory safety (Flinn, 2006). A major factor in lab safety is the number of students in class. The National Fire Protection Association (NFPA) requires 50 ft^2/person in labs used for educational purposes (NFPA, 2006). This amount of space improves traffic flow, student supervision, and overall control. Assigning more than 24 students to a lab can result in an increase in discipline problems and result in unsafe conditions (Flinn, 2007). Inflexible space encourages teachers to remain at the front of the room separating the teacher from students using chemicals, scalpels, and electrical equipment.

PERSONALIZATION

The public has consistently reported in polls and studies that educators can do a good job and form meaningful links with students. "(People) have confidence in schools and school districts when buildings are well maintained with bright, clean interiors; when there are committed, competent, and caring educators; when quality education is offered; when there is good discipline in a safe environment; when schools contain achievement-oriented students, have involved parents, and offer a selection of optional programs and activities to meet special needs and enhance the growth of all students" (Carol & Cunningham, 1984, p. 122).

Parents are convinced that teachers make a significant difference in schooling. They see educators in high-confidence schools counteracting the impersonal character of institutional life by providing students with meaningful contacts with significant adults. Many adolescents in American high schools complain that they have little personal contact with anyone other than peers. Educators can recognize the isolation many students feel and devise means to provide them with close contact with adults (Wayson et al., 1988). "Staff members in high-confidence schools use the physical facilities in ways that enhance and reinforce relationships. These schools are attractive, clean, and welcoming. Both students and staff accept responsibility for keeping them that way" (Wayson et al., 1988, p. 61).

The National Association of Secondary School Principals (NASSP) has recommended that personalization and interactions between teachers and students be increased; students need trust, closeness, genuineness, a sense of caring, and meaningful contact with adults. Caring interactions help students believe that they have a personal adult advocate (PAA) who is truly interested in their concerns (NASSP, 2003). Personalization involves active listening, respect, courtesy, and fairness (Mawhinney & Sagan, 2007), and student-teacher communication held at a distance of 1.5-4 feet so students can feel connected to and feel supported by staff (ASCD, 2007). Science labs, often with a fixed demonstration table and desks defeat personalization when students are forced to be 12 feet or more from the teacher in a science classroom (Duncanson & Achilles, 2007). A distance of 12 or more feet between persons makes personalization difficult to achieve. Teachers who know their students and allow the students to know them find that they begin to treat each other as human beings (Mawhinney & Sagan, 2007). "Teachers are in uniquely powerful positions to positively impact youths who are at risk for school failure. Youths who overcame serious risk factors often report that a teacher, coach, or other adult provided a mentoring relationship that sustained them. Developing classroom routines that meet the needs of all students is an essential first step" (Rockwell, 2006, p. 17).

THE ROLE OF TEACHERS

Teachers can design classrooms and enhance student achievement positively and they need to recognize and act on opportunities to do so. "Teachers have a significant control over classroom adaptability, instilling a sense of personalization and ownership within their students" (Lackney & Jacobs, 2002, p. 1). Redesign of classrooms is a first step. "Structure must change before culture can change" (Ouchi, 2004, p. 18). Cultural changes do not happen overnight. "If you alter the structural arrangement and then have patience, within a year or two the culture will begin to change" (Ouchi, 2004, p. 20-21). This is not an easy process. Teachers resist making fundamental changes that make a significant difference in the essential practices of teaching and learning (Washor & Mojkowski, 2006). Change will occur one classroom at a time (VanHorn, 2006).

Improving personalization requires teachers to include students in the conversation about improving the classroom climate (Dudley-Marling, et al., 2006; Sommer, 1977). By engaging students in the process, a student-centered classroom can be created that will influence students' academics, behavior, and engagement in positive ways. Through trial and error teachers can establish new classroom designs to support learning and personalization. Students often want to put the teacher in the middle rather than on one side. Learning happens more in that kind of environment (ASCD, 2003).

DESIGN AND PROCEDURES

This action-research study followed Johnson's (2001) cross-sectional explanatory design format (Type 8) (p. 10). The researchers first established a framework from research, theory, and practice base, then observed a "grab" sample of 41 science labs in 4 high schools and 6 labs in one middle school. They conducted measurements and analyses of instructional space use relative to Hall's (1966) typology of space usage and key concepts of personalization (proximity), safety (lines of sight), and instruction. They engaged teachers in informal discussions of observations during "walk throughs" to validate their own conclusions. Conversations centered around room usage, teaching methods, and the strength and weaknesses of room design. The nature of the study makes generalizing results the reader's task.

FINDINGS

It is clear that one lab design does not meet the instructional needs of all sciences. Earth science teachers favor large desks that seat two students. The desks are useful in class where students may be using a text, notebook, and reference tables while engaged with instruction. The expansive desk tops provide ample space for map projects, soil analysis and examination of earth materials. Each desk should have an electrical outlet. The lab should include wide counters around the outside of the room to provide additional work space and include a small number of sinks. Biology teachers favor the same desks but require a larger number of sinks on the perimeter of the room. Chemistry teachers favor lab stations where students stand while working with chemicals. Each station needs to be supplied with gas, water and electricity. Physics teachers need solid lab stations and wide counters that are 12-15 feet long to accommodate specialized equipment.

Open floor space needs to be ample enough to prevent crowding but not so expansive that lines of sight are compromised. Lab activities often involve instruction and practice in the use of new, and expensive, equipment. Teacher supervision to minimize breakage and the occurrence of unsafe lab practices is favored when the space is just sufficient for the activity. Proximity and short lines of sight enhance student safety. Long distances and poor design force teachers to raise their voices. In addition, instruction is negatively affected when students who are furthest from the teacher do not pay attention. This is especially true in classrooms with a full complement of students. The average number of students in observed labs was 23. Teachers reported classes as large as 35. The observed designs influenced the teacher and instruction. On average, teachers provided directions/procedures to be followed 22 times/class. By contrast, teachers asked only five questions on a knowledge or comprehension level. Only one student asked a higher order thinking skill (HOTS) question. No teacher asked a single HOTS question.

Teachers spent their time reacting to student behavior. On-subject conversations did not occur. Instead, student and teacher interactions focused on directions and procedures. Lab facilities with fixed furniture arrangements hinder teachers from meeting NSTA (2002) recommendations flexible space. Teachers reported that newly built lab rooms with fixed furniture offered poor lines of sight (LOS), poor use of space, poor student control, unsafe conditions (e.g. students can 'jimmy' electrical outlets), and constraints on teaching methods to the degree that teaching is dictated by the space. Classrooms arranged vertically provided fair-to-good LOS (only a few students are outside a direct LOS). A demonstration table at the front of the room between the chalkboard and student desks immediately increased the distance between the teacher and student thus diminishing opportunities to promote personalization (Figure 1). When the room design is horizontal, a larger number of students fall outside the teacher's LOS resulting in a poor situation regarding safety. More space per student conveys a sense of trust which helps to foster personalization (Figure 2).

Teachers were observed using a wide variety of teaching methods. Forms of direct instruction included: explanation followed by a demonstration, student use of the information, and a formative assessment by the teacher; micro-teaching in 10 minute lessons; recitation; and demonstrations. Indirect instruction included teachers using several levels of inquiry (guided, discovery, challenge, and student initiated), cooperative learning, and independent learning. Some teachers described using new teaching methods to deal with safety issues created by the impersonal distances between students and the teacher. For example, chemistry teachers have moved to 'micro-chemistry' so they can bring students to small desks to enhance chemical safety while reducing the problem of chemical disposal. But students lose the WOW! factor associated with "test-tube chemistry," and do not develop laboratory skills and make real-world connections to their work. The researchers did not observe any teacher-student personal contact in any lab setting.

CONCLUSIONS AND RECOMMENDATIONS

New science labs have become larger to accommodate new design ideas but there have been some unexpected consequences of this trend. Appropriate instructional strategies, safety, and personalization have all suffered. Present lab designs force teachers to focus on teacher-centered methods to deliver instruction rather than using instructional methods that promote student inquiry. The need to use new instructional strategies to meet mandates for inquiry-based science has not been accompanied by a change in the design of science labs. The architecture creates problems: students are too far away from the teacher, sight lines are too long, instructional time is reduced, attention to classroom control is increased, opportunities for inquiry-based instruction are compromised, and meaningful student-teacher interaction is reduced. Dialog in large lab sections often is limited to a few low-level questions and a plethora of directions or procedures for students to follow. The horizontal layout described by Betoret and Artiga (2004) to promote a student-centered learning approach and high order thinking has not yet been fulfilled.

Teachers must be involved in the design of lab facilities that promote good teaching practices, safety, and personalization: "Spaces designed with learning scenarios in mind" (AAF & KnowledgeWorks, 2006,

p. 44). Science labs designed with a student-centered focus can accommodate a variety of learning styles and promote different forms of inquiry teaching. Teachers need to create environments that promote academic conversations with students no further than 8' away, a distance that enables teachers to speak in a normal tone, monitor student work, promote student inquiry, and assume the role of a PAA. Teachers need to be agents of change both individually and by working through professional organizations to encourage of cials to pay more attention to school learning conditions. The American Federation of Teachers (AFT) has recommended that the federal government should, "Require a 'learning environment index' be used. . ." (AFT, 2006, p. 12); administrators can show support for teacher's efforts by controlling class sizes and providing assistance in classroom design.

A well designed school must support teaching and learning. There is a continuing need to examine how architectural design and space use (proxemics) in uence teaching strategies and student achievement. "Given information they can act upon, teachers can effectively evaluate their own classroom environment and plan how to use space. Individual mentoring, administration-provided incentives, and time can entice a faculty to design settings that improve student achievement" (Duncanson & Achilles, 2006, p. 9). *The center for school improvement* resides in classrooms.

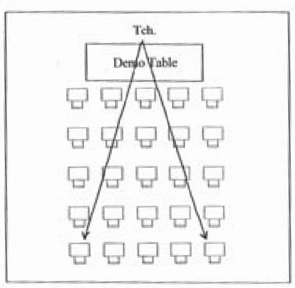

Figure 1 Science Laboratory

Fair to Good Lines of Sight (LOS)
Poor Personalization

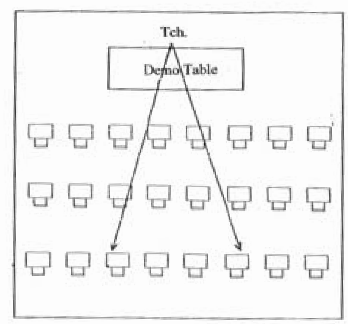

Figure 2 Science Laboratory

Poor Lines of Sight (LOS)
Fair Personalization

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