Prototypical Laboratory Design to Support Learning and Teaching

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ABSTRACT

Collaboration between designers and scientists is an unusual combination to undertake the prototypical design of a teaching laboratory funded by Howard Hughes Medical Institute. The zoologists are developing a cooperative learning and interactive teaching pedagogy to make learning science a process of critical inquiry and discovery. The industrial and interior designers are paying attention to the design issues of function and environmental support for teaching and doing the work required in a three-hour, hands-on beginning science learning space. Using both qualitative and quantitative research methods, the designers are able to determine a framework for making design decisions in prototypical beginning science environments. This framework is being developed as a guideline for designing similar environments at other institutions of higher learning. Videotape analysis precedes the research to uncover the underlying problems of the existing space and to formulate the questions for the research. Elements of a case study and an evaluative study integrate with the design process to form the basis of an intensive investigation of design issues for a beginning science teaching laboratory. Using two pretests as a baseline, the posttest data evaluates the success or failure of the prototypical design. Both the pretests and the posttest evaluate the physical attributes of the old and new learning environment related to a beginning laboratory course in Zoology at Arizona State University.

1 INTRODUCTION

A multidisciplinary approach to designing a laboratory used by beginning science classes for university education is an unusual attractor for funded grants. Linking design of the physical space to how the instructors and students use the space is not a new perspective to making design decisions. The novelty of this project is using several research methods to discover user needs and designing the space to fit both instructional styles and learning styles.

The setting for this project includes multidisciplinary players. Two instructors from the second year zoology class want a new design to support interactive teaching and cooperative learning that accommodates the increasing role technology will play in the future. The head of the Zoology department wants the project to be a prototypical model that can be repeated by other universities. The manager of the project is extremely interested in economically pushing the envelope of laboratory design. The industrial designer and the interior designer want to provide an environment that creatively supports the work performed by both instructors and students.

The constraints of the project include remodeling an existing laboratory space in the basement of a building built on the campus in the early 1960's. There is no alternative to select another space for the new laboratory. In addition, the budget is moderate.

Zoology laboratories include typical scientific work with microscopes and slides, dissections of small- and medium-sized animals, solution mixes and all the scientific equipment associated with these types of work. In addition, beginning zoology education includes studying humans and the effect of activities on systems such as the heart and lungs. Since the most available human subjects are the students themselves, temporal space is provided for exercise bicycles and running in place to supplement the experiments in this segment of the coursework.

By the time the grant is funded, the cooperative learning/interactive teaching pedagogy for this beginning science class had been revised and refined by being taught for four years. During the programming stage of the project, no computers are used in teaching the course or learning the coursework. To better understand the cooperative teaching and interactive learning pedagogy, a comparison of traditional teaching and learning styles is outlined in table 1.

Table 1. **Differences between Traditional and Cooperative Learning/Interactive Teaching Goals**

TRADITIONAL	COOPERATIVE LEARNING/ INTERACTIVE TEACHING
• Teacher-centered	• Student-centered
• Knowledge is transmitted through lectures, texts, worksheets (Koschmann, et al. 1993)	• Knowledge is gained through the student's processes of investigation, discovery and application (Smith and MacGregor 1992)
• Individual work is the norm	• Peer group work is the norm
• The student assumes a passive receiving role	• The student assumes an active engaging role

In the science laboratory, teaching instruction at ASU has changed from the traditional method that emphasizes "teach them basic science, teach them the applied science, then give a practicum" (Harrison 1995). Students were told what to do and what the findings should be. In the new paradigm, laboratories are introductory activities that build direct experiences in which to understand procedures, concepts and theories being studied. Cooperative Learning and Interactive Teaching operates from the premise that "give them a problem, coach their problem solving, and then have them present their solutions and give the relevant theory" (Harrison).

From the instructor's perspective, there are three basic teaching components that must be accommodated in any instructional space.

- Both the instructor and the instructional material displayed must be visible.
- Space must be available for notetaking at student work areas.
- There must be an option to make several different types of presentations (slides, overhead projectors, whiteboards, etc.).

The addition of supplemental computer instruction in the science laboratory curriculum now includes the need for shared monitors and hard drives. The increasing technology possible for the new laboratory will pose its own set of criteria for designing the new space. Large computer monitors allow groups of students to see the result of program manipulations and to use this information as a basis for uncovering the answers to the problems posed. Hard drives must be readily accessible for students to download program information to their own floppy disks. The floppy disks will be used as class notes to study for exams or as a beginning point for further manipulation of data with a computer outside of class. Printers will need to be available for occasional printouts during class. One of the basic design problems is to provide computer workstations that are relatively safe in both a dry and wet laboratory environment.

2 STUDYING THE ENVIRONMENT

Design is one of those fields that is criticized for solving problems but rarely providing a framework for evaluating any difference that design makes in the outcome. Therefore, two components to this research project are necessary. One is qualitative--discover the design issues rather than approach the situation with a standardized set of typical issues. The second is quantitative--test the new design to see if it makes any difference to the people using the space. The two designers in this project are not specifically trained in science laboratory design. In this case this is positive asset to the research. Brenner (1987) notes that researchers studying environmental design bring to the process "a set of values, preferences, attitudes, and limitations" which they have shaped over the years in design settings. Neither one of the designers in this case brings with them the baggage of what components make good or bad science laboratory design.

Interviews with the instructors and the rest of the zoology partners reveal two things: the problems with the existing instructional laboratories and expectations for the future laboratory. How the laboratory is actually used by instructors and students is not apparent. The researchers make the decision that it is impractical to interview students whose focus in on meeting science course criteria rather than participating in design research. Therefore, two methods of observation are adopted to study laboratory use. The design research team makes several observations of distinctly different laboratory sessions. In addition, videotape cameras are mounted in the ceiling of the classroom to record what instructors and students do during laboratory sessions.

The combination of interviews, observation, videotape analysis and measurement of the existing conditions supply a rich base for designing a creative, functional and aesthetic environment. Testing the old design and the new design will give the both the zoologists and the designers valuable information about what to do the next time a space like this is designed.

3 REFINING THE DESIGN PROGRAM

The outcome of reviewing several representative video segments in minute detail reveal that both instructors and students use the space in a slightly different manner than the interviews and observations suggest. Information gathered on grouping tendencies and the most frequent group sizes varies considerably between interviews, personal observations and the videotapes. The interviews and personal observations reveal that the most common group size is four people. Groups of students also meet in threes and fives for peer collaboration. The videotape reveals that there is no common group size. Group sizes vary between two, three, four and six people on a relatively frequent basis in the cooperative science environment. Both the zoology instructors' descriptions and the designers' observations of laboratory sessions conclude that four-person groups occur most frequently. This point of view is also supported by the interactive teaching and cooperative learning literature pertaining to other types of learning environments, but not specifically to the science laboratory. The videotape reveals that two-person groupings are the most frequent, followed by three-person groups as the next most frequent.

Another revealing fact emerges from the videotaping research. A piece of that baggage than Brenner referred to is the almost subliminal concept that in interior environments people communicate across the tops of tables, desks and other flat surfaces. The videotape reveals that furniture gets in the way of communication. If a classroom could be designed without furniture, it might promote closer cooperation among people. The furniture in the classroom being videotaped is an obstacle to communication. People lean on it to get closer face-to-face contact. Students sit on top of it to be included in the group. Basically, the furniture is necessary to hold student notebooks, belongings and the scientific laboratory equipment. The students literally contort their bodies around the unmovable furniture to do their work in the laboratory. Human factors are not being accommodated in the existing laboratories. In fact, Robert Sommer identified in 1969 that good design sometimes considers people to be adaptable to their environments. He whimsically reshapes the question: "The . . . . question is not so much what sort of environment we want, but what sort of man we want" (p. 172).

4 SELECTING THE ELEMENTS TO BE EXAMINED IN THE PRETEST AND POSTTEST INSTRUMENT

The questions asked on the pretest/posttest instrument are directly related to information gathered from observations, interviews and videotape. The questions reflect the type of programming information needed to design the laboratory.

The questionnaire instrument uses a five point Likert scale in the first part. The questions query students about different aspects of the existing learning environment. Each of the questions can pertain to other similar teaching laboratories located at other institutions. They question:

- using standard laboratory fixtures;
- whether lighting glare affects instructional activities in the space;
- circulation factors;
- group viewing of instructional demonstrations;
- acoustics in the space; and
- different conditions for instructor and student interface.

The second part of the student questionnaire uses multiple choice responses. The questions ask the student to supply personal information about:

- demographics;
- their individual learning styles; and
- the amount of in-class time they spend doing specific types of lab-related activities.

Wener (1988) said, "Pretest posttest studies can serve as a check on the reasonableness for design-behavior assumptions." Evaluating the impact of the physical changes in the teaching laboratory space is accomplished by doing a pretest and a posttest. Although the questions on the test instrument remain the same, the conditions of instruction and learning vary between the pretest and posttest populations. All the classes participating in the pretests and posttests have the common denominator of using the cooperative learning and interactive teaching pedagogy. In addition, the same course is taught in all the teaching laboratories participating in the tests.

Two pretests assist the investigators in determining if changes to the physical environment improve or impair teaching and learning styles. The first pretest questions students who have not yet used the computer as a learning supplement in the beginning zoology course. Sixty-three (63) respondents participate in the questionnaire process. For the purpose of this study the first pretested laboratory will be called LABORATORY #1. In this case, the laboratory work includes workbook instructions, typical scientific method exercises, comparisons of experiment results with the experiments the student is doing, small animal dissections, short teacher-centered demonstrations, and short class chalkboard and overhead projector instruction. The classroom space is traditional with fixed long laboratory tables at stand-up height, typical institutional finishes and lighting from the 1960's, backless high metal stools for seating, and teaching aids for face forward instruction. Equipment for the exercise-related classwork is stored around the perimeter of the room until needed.

The second pretest questions students who are using computers for the first time in the course to supplement their learning. One hundred and thirty-one (131) respondents participate in the questionnaire process. For the purpose of this study the second pretested laboratory will be called LABORATORY #2. The laboratory is taught in an unrenovated laboratory that has freestanding laboratory tables that accommodate 4-6 students each. The laboratory tables are lowered to standard desk height, and low metal stools serve as seating. The computer hard drives, monitors, keyboards and mice sit directly on the tabletops. Four computers occupy each of three tables in the laboratory. Three other tables provide working space for non-computer activities. Each table with four computers is arranged with two computers on one side of the table facing two computers on the opposite side. Minimal space is available for two students to view the computer screens at the same time. The curriculum has been altered in the course to include computer-assisted instruction and learning. In addition, computer-assisted instruction had alleviated the need for whole small animal dissections. Only small animal parts were dissected in the class. Partly attributed to the introduction of computer-based work, the instructor and student relationship involves an increase in one-on-one mentorship, and students interface peer-to-peer considerably more than in Laboratory #1. Occasional front-of-the-room instructions are delivered for 5-10 minutes during a three-hour laboratory period. The computer workstations are not subject to wet conditions since the non-computer work is done at three other tables in the laboratory. The semi-traditional laboratory setting has a fixed counter with a sink and a place for distributing instructional materials. This counter occupies a space at the side of the teaching laboratory area. The blackboard, however, is located behind this counter and requires that students focus their attention to that side of the room for blackboard information. There are no special media accommodations in the room except a pull-down projection screen in front of the blackboard. A portable, stand-alone computer and video projector is used about 15% of the time when instructional material is being dispersed to students. All exercise equipment used for laboratory work is stored elsewhere.

The posttest is given to students using the newly designed laboratory after it is open for three months. One-hundred and nine (109) respondents participate in the questionnaire process. For the purpose of this study the posttest laboratory will be called LABORATORY #3. At the end of the three-month period of time the laboratory routines for both students and instructors have become normal in the newly designed space. The curriculum includes computer-supplemented instruction, a variety of media presentation methods, dissections of very small animal parts, examining human cadavers to study how individual organs are related to the human body, and traditional scientific comparison activities. Workstation pods, containing space for both lab work and computer hardware, provide space for eight students each. The computer hard drives with monitors on top sit on a 1" thick surface that raises them out of pooling liquids. The keyboard, which also sits on the worksurface, includes a rolling ball mouse and is covered with a protective plastic cover to counteract liquid spillage. The instructional space is near the center of the room, and a two-faucet sink occupies a centralized location on one side of the room. The teaching station and supply distribution table is mobile. Although it is not currently being used, a ceiling-mounted video projector bracket is available, as is a floor outlet and network connection near the center of the room. The computers are networked to a server, and the instructor's computer can be networked to each student's computer, or it can be used as a stand-alone unit. One third of the exercise equipment is stored in the room and the rest is stored elsewhere. Computers are distributed strategically throughout the room and the workstations are designed for the work process in the laboratory.

5 RESULTS OF THE PRETESTS AND POSTTESTS THAT AFFECT THE DECISION-MAKING PROCESS IN DESIGN

Three areas of evaluation directly relate to designing similar teaching laboratories in the future. The types of teacher and student interface during a class can be questioned in other similar teaching laboratory environments. In addition, the visibility of media presentations for instructional material, and how easy or difficult it is to circulate in the space when the laboratory is in use can be questioned.

Media presentations in the new laboratory environment include slide, overheads and projected computer images and information. General information and detailed scientific methodology is frequently given to the whole class by writing it on a blackboard or whiteboard. The pretest/posttest questions are asked in connection with the lighting conditions in the laboratory setting. In Laboratory #1 media is limited to blackboards and a projection screen located at the front of the room. Portable overhead and slide projectors are moved into the room when required. The lighting is vintage 1960, four-tube fluorescent fixtures with flat plastic lenses placed in the typical 4' end-to-end with 6' side-to-side spacing. The lighting is turned on or off by two switches near the door. In Laboratory #2, the blackboard and the projection screen are located on the same side of the instructional space and portable equipment is moved into the room when required. The lighting in Laboratory #2 is the same as in Laboratory #1. Laboratory #3 has, near the center of the room, a movable media board with a fixed, ceiling-mounted projection screen that can be rolled down when needed. The media board is networked to each computer in the laboratory space. In addition, two large marker boards are accessible to each group workstation. The room has trough lighting with parabolic louvers around the perimeter of the room, four recessed medical lights near the center of the room, and three-tube fluorescent lighting with parabolic louvers for general lighting. The lighting in Laboratory #3 is adjustable to five different preset lighting combinations plus an all off option. The first general lighting scheme uses fluorescent room perimeter lights only. The second scheme uses medical lighting in the center of the room with perimeter lights. The third scheme operates general fluorescent lighting only. A combination of medical lights and general lighting is scheme number four, and a combination of all three types of lighting on at the same time is scheme five. The general fluorescent lighting is dimmable if needed.

Types of student and teacher interface occur in six categories of interaction:

- help with understanding the theory of the laboratory;
- help with laboratory experiments or investigations;
- help with using the computer;
- help with using the computer programs;
- helping the student individually; and
- helping the group.

Comparing the frequency rates reported by the questionnaire respondents for these six types of interaction helps the designer identify paths of frequent circulation for the instructor. In addition, the needs for cooperative group spaces can be partially determined. These design criteria can be generalized to support decision making for other beginning science laboratories.

6 PRETEST AND POSTTEST RESULTS

In the two pretest groups and posttest group, respondents to the questionnaire report that between 10% and 12% of class instruction is spent in extremely frequent or frequent interaction with the instructor about the theory of the class. An equal percent of instruction is done at the student's work area when laboratory experiments and investigations are in progress.

Since Laboratory #1 did not have computer-assisted instruction, the two questions about the computer hardware and software can only be compared for Laboratories #2 and #3. Both of these laboratories report 9% to 12% of class instruction is spent in extremely frequent or frequent interaction with the instructor about the computer equipment or the programs used in the laboratory.

Laboratory #1 and Laboratory #3 respondents report about the same rate of extremely frequent interaction (22%) with the instructor for group help. However, Laboratory #2 reports only 20% extremely frequent or frequent interaction with both group and instructor. On the other hand, student and instructor interaction for personal help decreased slightly to 20% in Laboratory #1 and Laboratory #3. Personal interaction with the instructor also decreased proportionally to 18% in Laboratory #2.

Questions about media presentations and lighting report existing conditions. If a difference can be found between the combined reports of glare in Laboratories #1 and #2 and the posttest of Laboratory #3, the outcomes can be used as design tools for the another laboratory.

- Does the lighting cause glare when slides and overhead projections occur?
- Does the lighting cause glare when whiteboard or chalkboard information is presented?

Laboratories #1 and #2 report that 35% of the time the lighting in the room interferes with the visibility of slides and overhead projections. Seventy-eight percent (78%) of the respondents report that the lighting in Laboratory #3 rarely or very rarely interferes with projected images and information.

Similarly, Laboratories #1 and #2 report that between 29% and 38% of the time lighting in the room is an impediment to seeing the whiteboards and chalkboards. Laboratory #3 reports 80% satisfaction with the presentation of written materials by these two methods.

Potential circulation obstacles question the use of an essential sink(s) within each laboratory and the ability of students to move through the laboratory during class work. Knowing that the sink is essential to dissection work, the frequency if its use is measured. Other conditions in the laboratory that occur frequently are gleaned from the videotapes. One of the conditions is that people bump into other students when their hands are full of laboratory equipment or supplies. Another circumstance also shows on the videotape and in personal observations--aisles and pathways in the classroom are frequently obstructed.

This part of the questionnaire demonstrates a substantial tool for studying circulation in teaching laboratory environments. The frequency of sink use varies significantly in all reporting categories in Laboratory #1 with 29% of the respondents selecting sometimes use the sink(s) and 52% reporting very rarely or rarely. In Laboratory #2 sometimes and very rarely were 19% and 34%, respectively. However, in Laboratory #3, 70% of respondents very rarely or rarely used the sink(s). This can be interpreted that sink use decreased significantly between Laboratory #1 and Laboratory #3. It is probable that the decrease of medium size animal dissections in Laboratory #2 and the addition of observation studies with human cadavers may contribute to the reduction of sink use in these two laboratories.

When the respondents are questioned about the two circulation factors, significant discrepancies highlight design decisions. In Laboratory #2, students report that 64% bump into other people while moving through the aisles or carrying equipment or supplies from place to place. Laboratory #1 respondents estimate 45% of the time they bump people extremely often, often or sometimes. Laboratory #3, however, reports 65% rarely or very rarely bump into anyone.

Circulation in the aisles and pathways report similar findings as the "bump into people with their hands full" above. Laboratory #2 reports the most difficulty in navigating the aisles and pathways with 79% of the respondents reporting difficult or very difficult. Laboratory #1 reports 75% difficulty. Laboratory #3 respondents report 54% extremely easy or easy in navigating through the new laboratory thoroughfares. The first laboratory has immovable tables in long, straight rows. The second laboratory has smaller rectangular tables that seat 4-6 people. The third laboratory has tables with undulating shapes. The new laboratory has improved circulation in two different ways.

7 ESTABLISHING GUIDELINES FOR OTHER UNIVERSITIES WITH SIMILAR LABORATORY SPACES

Valuable guidelines for other universities to use in studying proposed designs for teaching laboratories have emerged in the ASU process of design decision making. The multidisciplinary team is using the following questions to evaluate the design decisions in the new laboratory space:

- Does the design support instruction and curriculum?
- Does the design support the students and learning?
- Does the design support the personnel who supply and maintain the laboratory over time?
- Does the design support students with different mental and physical abilities?

If the design solutions can be described in these terms, then it is possible to combine these different goals to examine if they endure as design issues that are solved in the new space. For instance, how does the design support the curriculum and learning? How does the support personnel, who are needed in some experiments, use the space when instruction is going on? Are the teaching and learning spaces accessible and useable by people with different abilities? Is the maintenance required for the laboratory practical based upon the people who maintain, repair, and reconfigure it over time? These are complexities that a designer may not be aware of and that the scientists don't know to ask when decisions are being made in the design process.

8 FUTURE WORK TO BE DONE TO EVALUATE SIMILAR ENVIRONMENTS

The current dilemma of evaluating whether or not design makes a difference in environments is difficult to pin down. In design, researchers are frequently dealing with evaluating spaces that are in transition. It is very difficult to control the current environment the sample population lives in during the testing period unless a longitudinal study is done over time and test conditions remain unchanged. Therefore, research that captures a snapshot of now has different dependent and independent variables to compare. The three different conditions in the study of laboratories #1, #2, and #3 offer snapshots of a constantly changing delivery of beginning science education. This research shows comparisons between the space and the people using it in three different transitions. The two pretests are given to classes that have no computer instruction in a traditional laboratory setting and to the first class using computer-aided instruction in a slightly non-traditional laboratory space. The posttest is given to the first class using the new space with fully networked computers and the ability to download information directly from an electronic media board. The results of this study only help identify recurring issues that occur when designing beginning science teaching laboratories. This is helpful for building a beginning base of knowledge that needs more definitive research methods and testing criteria in the future.

The design team for this project : Lorraine Cutler, co-principal investigator (interior design); Lauren McDermott, co-principal investigator (industrial design); Michael Kroelinger, lighting consultant and test instrument designer; Graduate Research Assistants: Gulnar Bhagwagar, Abhas Jain, Sarat Kanakamedala

9 REFERENCES

Brenner, D. (September 1987) Minds over matter, *Architectural Record* 175:10, pp. 103-108.

Bruffee, K. (1993) *Cooperative Learning.* John Hopkins University Press, Baltimore.

Harrison, J. (February 1995). Personal interview Arizona State University.

Koschmann,T., D. Newman, E. Woodruff, R. Pea, and P. Rowley (October 1993) "Technology and pedagogy for collaborative problem solving as a context for learning: Report on CSCW '92 workshop." *SIGCHI Bulletin* 25:4, p. 57-60.

Lieberman, A. (1992) K.Rehage (ed.). *The Changing Context of Teaching.* The National Society for the Study of Education, Chicago.

Smith, B. and J. MacGregor (1992) A. Goodshell (ed.) *Cooperative Learning: A Sourcebook of Higher Education.* National Center of Post Secondary Teaching and Learning Assessment, University Park, Pennsylvania.

Sommer, R. (1969) Personal Space the Behavioral Basis of Design. Prentice Hall, Inc., New Jersey.

Wener, R. E. (Winter 1988) Doing it right: Examples of successful application of environmental-behavior research. *The Journal of Architectural and Planning Research* V5:4, p. 284-303.