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ABSTRACT

Intended to assist educators and trainers who must make recommendations about facilities to architects and school authorities, this ERIC information analysis project summarizes research on the design of both classrooms and individualized learning spaces that will optimize learning. Six teaching/learning space topics are considered: (1) light and color; (2) heating, ventilation, and air conditioning; (3) acoustical and background noise; (4) furniture and ergonomics; (5) electrical wiring and conduit requirements; and (6) computer requirements. The relationship of physical properties of learning facilities and behavioral science data is considered, and the specific environmental variables that influence the student--temperature and humidity, noise, light and color, seating position, classroom design or openness, density and privacy, and the presence of windows--are discussed. Research findings on requirements for materials storage, minimum light for learning spaces, colors and learner activity, and ideal temperatures for student activities are summarized in four tables, and diagrams of classroom space configurations for various audiovisual media are provided. (116 references) (EW)

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INSTRUCTIONAL FACILITIES FOR THE INFORMATION AGE

by

Frederick G. Knirk

ERIC Clearinghouse on Information Resources

Syracuse University
December 1987

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FOREWORD

The teacher, the learner, and the materials are usually considered to be the basic ingredients of the teaching-learning process. Each is a vital element, but the environment in which the process occurs is often neglected; this monograph focuses on environments or learning spaces in which the teachers, learners, and materials interact.

There was a surge of interest in the design of learning spaces in the 1960s and early 1970s when hundreds of new schools were being built. The Ford Foundation established the Educational Facilities Laboratories to provide guidance to architects, professional educators, and school boards on new aspects of building schools. One of the paramount concerns of that era was provision for the new media and technologies that were being introduced, and which promised to be around for the life of the building. Therefore, such matters as conduits for closed ciruit television, light control, and screen placement were considered to be important factors.

As school building declined in many parts of the country in the late 1970s and 1980s, little attention was paid to the rapid increase of information technology—i.e., the combination of computing and telecommunications—in the schools. As school building is increasing in the late 1980s and as older buildings are being renovated, once again the concern for adequate planning to handle these new technologies arises. But the organizations and publications of the previous decades are either not available or sufficiently up-to-date to serve a new generation of architects and school people. The literature exists in some journals, some relatively inaccessible reports, and in the ERIC database, but it has not been analyzed and organized for easy use.

Professor Fred Knirk of the University of Southern California has been systematically reviewing this literature for more than two decades. He has published widely and has served as a consultant to businesses, schools, and military organizations on the design of environments for learning. When we asked him to pull together the current and relevant information in this area, he was pleased to do so. This monograph is a major contribution to the people who are responsible for designing contemporary facilities for today's learner using today's technologies.

Donald P. Ely
Director, ERIC/IR
Syracuse, New York
December 1987

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INTRODUCTION

The purpose of this document is to summarize the research or knowledge concerning the design of spaces to optimize learning. Classroom spaces and spaces for individualized learning are both considered. The evolving use of computers in schools requires special lighting, ventilation, and wiring considerations, and will be emphasized in this document. Although projection equipment and display screens for viewing visuals are an old problem, there is some new knowledge about this topic and it will be summarized as well.

Specifically, this ERIC Information Analysis Product focuses on six teaching/learning space topics: (1) light and color; (2) heating, ventilation, and air conditioning; (3) acoustical and background noise; (4) furniture and ergonomics; (5) electrical wiring and conduit requirements; and (6) computer requirements.

Student learning environments reflect a large social investment. However, it is an important investment since the more facilitating the learning environments, the greater the probability that learning will occur within them. The design and selection of visual, acoustical, thermal, and relational factors affect each individual in the school. Each of these variables must be considered when designing solutions for instructional problems.

School building environments have an impact on student learning, affect, and physiology. The specific environmental variables that can influence the student are temperature and humidity, noise, light and color, seating position, classroom design or openness, density and privacy, and the presence or absence of windows.

The design of learning spaces for cognitive, affective, and psychomotor objectives is an instructional technology. Behavioral science data regarding color, form, acoustics, light intensity, light contrast, and temperature can be used in ways which will predictably affect learning. Educators and trainers need to know why to recommend specific facilities and must communicate these needs or specifications to architects and school authorities. Form should follow function! Too often a new school is built by architects more interested in designing beautiful buildings than an environment for an instructional curriculum. In this publication the environmental factors that facilitate or inhibit student learning and affect will be explored.

COMPUTERS AND FACILITIES REQUIREMENTS

Computers are exceptionally effective as information storage and retrieval aids. In this section their facilities and equipment specification requirements will be examined in detail.

Computer users have long suspected that working with a computer is tiring and difficult: aching back and wrist muscles, tired eyes, and a feeling of general fatigue are common. The problem has been researched by a diverse group of individuals and organizations. These studies generally conclude that the reason for tired muscles involves the intensity of the work done on computers, and associated deadlines (Rowinsky, 1987a, p. 99). Human factors considerations such as user video display terminal (VDT) viewing distance, angle, resolution, and dot pitch are more important than generally recognized.

Monitor Selection Considerations

Radiation hazards when using computers is an issue that should be understood before these tools are used in schools. Current research on this issue indicates that students and teachers have little to fear from radiation. "On the basis of existing evidence, there appears to be no radiation hazard from VDTs" (Johnson, 1983, p. 1). Meyer, director of public information for 9 to 5: National Association of Working Women, also says that VDT radiation is very weak and implies it is no threat to computer users (Rowinsky, 1987b, p. 99).

In 1981, the National Academy of Sciences in Washington examined the evidence supporting claims of cataracts and other potentially related health problems, and determined that the amount of ionizing and non-ionizing radiation emitted by VDTs was too small to pose a threat of either cataracts or birth defects. Many studies are currently being performed to determine the long-term effects of ultraviolet and radio frequency wavelengths given off by VDTs at extremely low levels. It seems improbable that their findings will have an impact on educational uses of computers. "The amount of ultraviolet light of certain frequencies emitted by fluorescent light bulbs, for example, is 10 times greater than for VDTs," says William Murray, who has conducted a number of field studies on VDT radiation levels. Dr. Murray also says that the level of X-rays is barely distinguishable from background levels and the amount of infrared is far below the standards set by the National Institute for Occupational Safety and Health Panel on Impact of Video Viewing on Vision of Workers (Leeper, 1983).

Measurement of focus of accommodation using the field laser method shows no differential eyestrain effects, either in near points or accommodation and convergence or in focusing accuracy between individuals reading from hard-copy or from VDTs (Hedman & Briem, 1984). This study was carried out at the Swedish Telecom Directory Enquiry Centre on 29 operators. The fourth study by Starr (1984) at AT&T Bell Laboratories found that groups exhibited few differences in the likelihood and intensity of on-the-job physical discomfort, and no differences in the perception of discomfort that lingered after work. Differences were found in job satisfaction and concerns over job security, but most of these favored VDT users.

With regard to visual disturbances caused by watching VDTs, Johnson (1983) concluded that people working with VDTs "report discomfort or difficulty with their eyes more often than other workers with visually demanding jobs" (p. 1). He suggests five minimal criteria for the VDT: (1) the image should not flicker; (2) the entire display should be in sharp focus (no blurred edges); (3) the contrast between light and dark areas should be at least 8 to 1; (4) the characters should be formed by a 5x7 dot matrix at the very least (5x9 is becoming the standard); and (5) brightness and contrast controls should be easily adjustable by the VDT user.

Character displays composed of a 5x7 dot-matrix are barely satisfactory for continuous use. In fact, 7x9, 9x13 and 11x15 dot-matrix sizes are available and are better for student users. As the definition increases the ease of viewing tends to increase as well (Pastoor, Schwarz, & Beldie, 1983).

The *size* of the VDT display for classroom computer terminals needs to be considered. The German (Deutsch Industrie Norm; DIN) standard calls for a 15-inch VDT screen. This size is thought to reduce eye strain. Insufficient research is available, however, to help educators feel comfortable in selecting a 9-inch, 12-inch, 13-inch, or 15-inch VDT.

The *color of a monochrome VDT* monitor makes little difference to most learners. There are three primary choices of VDT monochrome screens for classroom use. These are the black-and-white, green, and amber screens. The choice of one phosphor versus another is fairly complex. Light consists of energy at various wavelengths, and it is the wavelength composition of light that determines which color we see. Light consisting of short wavelengths appears blue and long wavelengths appear red. The human eye is not equally sensitive to all wavelengths of light, i.e., we are not very receptive to deep blue or deep red, but the eye is quite sensitive to the yellow-green region of the spectrum. White, green, and amber phosphors all generate light energy from this region. The German (Deutsch Industrie Norm; DIN) standard requires no red or blue characters and claims that the eye has trouble focusing on these colors.

If the students are to use the VDTs in dim light conditions, then white light should not be used. To achieve good acuity, the eye must form a sharp, well-focused image on the retina. It is optically impossible for the eye to bring all wavelengths of light into sharp focus at the same time, a limitation known as "chromatic aberration." White letters are the most susceptible to these effects as white light consists of wavelengths from the entire spectrum. When you are working under normal levels of illumination, this is not a problem as the eye will improve the focus by constricting and prevent light from passing through the peripheral portions of the lens where chromatic aberration is greatest. Under dim illumination, the pupil dilates and blurred letters occur.

Consider the classroom walls and flooring color in selecting a CRT phosphor. Due to "color adaptation," the eye loses some of its sensitivity to the predominant color after time. If green is predominant you should choose either amber or white phosphors. If there is a lot of action on the screen, however, the green phosphor has a shorter persistence for most people and is more desirable in these conditions. White characters on a black background are relatively easier on the eyes than vice-versa.

Existing research studies do not conclude that human performance is significantly affected by green or amber or any other phosphor color. Personal preference polls suggest there is no agreement among users as to the best VDT color. None of the phosphors has an undisputed advantage, so the users should be involved in the selection to indicate what they affectively prefer whenever possible. The color of the VDT phosphor is not important—what is important is the lack of flicker, the resolution, and the contrast.

Design Considerations for Displaying Images on Computers

A number of studies have examined the possible fatiguing effects of using VDT terminals. The following studies investigate the effects of using VDTs as opposed to working with hard copy on typical work tasks. Gould and Grischkowdky (1984) studied 24 IBM participants who proofread from a VDT on one day and from hard copy on another day. They found no changes throughout the study in participants' proofreading performance (speed and accuracy), feelings (about the comfort of their eyes, body, mind, and work), or vision (acuity, contrast, and flicker sensitivity) that could be attributed to using VDT terminals. It is interesting to note that in this study they found the participants did proofread from hard copy from 20% to 30% faster than from a VDT.

When students were asked to read either from a low resolution 40 characters per line VDT display (typical of early personal computers and those which use a television set as a monitor) or from a book for two hours, they experienced little nausea or headache in either condition (Muter, Latremouille, Treurniet, & Beam, 1982). There were no significant differences between the book condition or the VDT condition on physiological or comprehension measures. VDT subjects read 28.5% slower than the book subjects. The authors suggest three reasons for these slower speeds: (1) the subjects were familiar with books and reading from books but not from VDTs; (2) the books had approximately 400 words per page and the mean number of words on the video page was approximately 120, and subjects may have a tendency to read pages at a fixed rate; (3) the number of characters per line differed in that the low resolution VDT had a maximum of 39 characters per line and the book condition approximately 60.

A study by Kruk and Muter (1984) similarly found that individuals read 24% slower from a VDT than from a booklet. Neither changing the distance between the reader and the VDT from 40 to 120 cm, nor increasing the contrast ratio in the video condition from 4.6:1 to 8.3:1 had any effect on reading speed. Single spacing on the VDT, however, produced reading that was 10.9% slower than that produced by double spacing.

A continuing problem affecting the future use of VDTs lies in the repeatedly researched fact that students *read more slowly* from a VDT display than from paper. While no one variable accounts for the relative inefficiency of reading from a VDT, it is probable that the problem centers on image quality. If this is the case, new VDT developments may reduce this problem with using VDTs for instruction in the future. The quality of the character matrix positively correlates with the time required to read a VDT (Pastoor, Schwarz, & Beldie, 1983). But even with a high quality display, reading from a VDT is not as efficient as reading from paper copy. Contrary to this reading conclusion, most businesses find that using a computer to display forms, directory information, or similar visual information is at least as effective as using printed sources of information (Starr, 1984; DeGroot & Kamphuis, 1983).

Another study of reading on a VDT found students were 17% faster with 80 characters per line than with 40 larger characters per line. Subjects were free to adjust their posture in both conditions, but only in the book condition were they able to adjust the distance from their eyes to the reading material, as well as the height and the angle of the reading material. The use of the character "9" which was required to fill the screen in this treatment may have distracted the subjects in the VDT condition. In the video condition, the presence of proportional horizontal spacing had no effect on reading speed or comprehension. This study suggests that extended reading from television screens or computer VDTs is certainly feasible (Kolers, Duchnicky & Fergusen, 1981). Another study of column width found that full and two-thirds screen width lines or columns were read about 25% faster than narrower lines filling one-third the screen width. It also found that text with a density of 80 characters/line was read 30% faster than text with only 40 characters/line (Duchnicky & Kolers, 1983). These studies suggest that 40 character per line monitors should be discarded for educational purposes and replaced with 80 character per line VDTs.

The following three issues, text justification, windowing and upper and lower case considerations are not facilities considerations, but human factors related to computer software selection concerns. It appears that students can read printed *ragged right margin text* faster than text that is fill-justified (extra spaces between words). No differences in comprehension (recognition questions) are usually found (Trollip & Sales, 1986). As we have seen, many factors influence a student's relative reading efficiency via VDTs.

It is not clear whether CAI or word processing displays should be designed for *scrolling or windowing* VDT displays. Studies have been conducted to determine the optimum mode of operation of the "scroll" keys on a VDT. One mode involves scrolling up the data to display data toward the end of the file. The other involves repositioning the entire VDT onto an adjacent portion of the file. A total of 281 novice subjects (11th and 12th graders) indicated that in most cases, subjects in the window groups performed significantly faster with significantly fewer moves than did subjects in the scroll groups. When allowed to "self define" the system, a significant majority of the subjects defined the system to window (Bury, Boyle, Evey, & Neal, 1982).

When studying the use of upper and lower case letters on the VDT it was found that college students using PLATO terminals could read upper case

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letters significantly faster. There was no difference in accuracy for sentences in either condition (Henney, 1981).

Students or teachers with *glasses* who are frequent computer users might consider obtaining a pair of glasses set to typical VDT screen reading distances to reduce eye-strain. Frequent users of VDTs might consider visiting their local drug store to obtain a set of 1 + or 1.5 + reading glasses to determine if they reduce eye strain. Some eye specialists prescribe medium range glasses instead of bifocals and may urge a gray tint. In Austria, workers who have problems focusing are given prescription glasses.

It is important that the office furniture be adjustable so that students who differ in size and often spend an hour or more at the computer without moving much can be accommodated rather than having to contort their postures in ways that produce aches and pains. For additional information on chairs, keyboards, and furnishings for computer users, see the appropriate section in this report.

Stress and the Student User

The worst computer related problem, according to Johnson (1983), is stress. Too often computer users are given an inadequate introduction to the computer and the new user becomes frustrated.

Individuals using computers for two to three hours are measurably fatigued (Mourant, Lakshmanan, & Chantadisai, 1981). The impact is greater for VDT viewing than for hard copy viewing. Fatigue, however, was found to be reversible when one hour breaks from the computer were provided. Kearsley and Hillelsohn (1982, p. 77), however, concluded that if an individual wants to spend many hours working at a computer terminal, it is possible without any real performance decrement although individuals will likely experience visual fatigue after a few hours without a break. Session length appears to be determined by the individual student and by the instructional designer in terms of motivation and content considerations.

Printer noise is usually annoying to all computer users. Although OSHA (Occupational Safety and Health Administration) suggests that only noise levels above 90 dBA can result in hearing loss, continual background noise levels of this intensity may result in individual stress and lack of concentration. The use of laser printers may dramatically reduce these annoying sounds.

Heat exhaust may also be a stressful problem. The heat generated by a VDT alone is equivalent to that of a 100-watt light bulb. The computer itself and the printers also produce heat. Multiple computers in a classroom can generate a lot of heat. To maintain a comfortable temperature level, circulation and/or cooling must be specifically considered for classrooms with computers.

Teachers, administrators, and curriculum designers/developers must take these computer-related potential problem factors into consideration when designing computer-assisted instruction (CAI) activities and provide for a variety of activities to supplement computer related activity. It appears today that potential health problems caused by computers can be averted. Lighting and furniture should be arranged or redesigned to prevent eyestrain and postural stress. Students should have a variety of activities so they can move about and work at variable paces.

The UAW (United Auto Workers) reports that by 1990, 75% of all office jobs will involve computers so schools must prepare students to use them (Waters, 1983, p. 70).

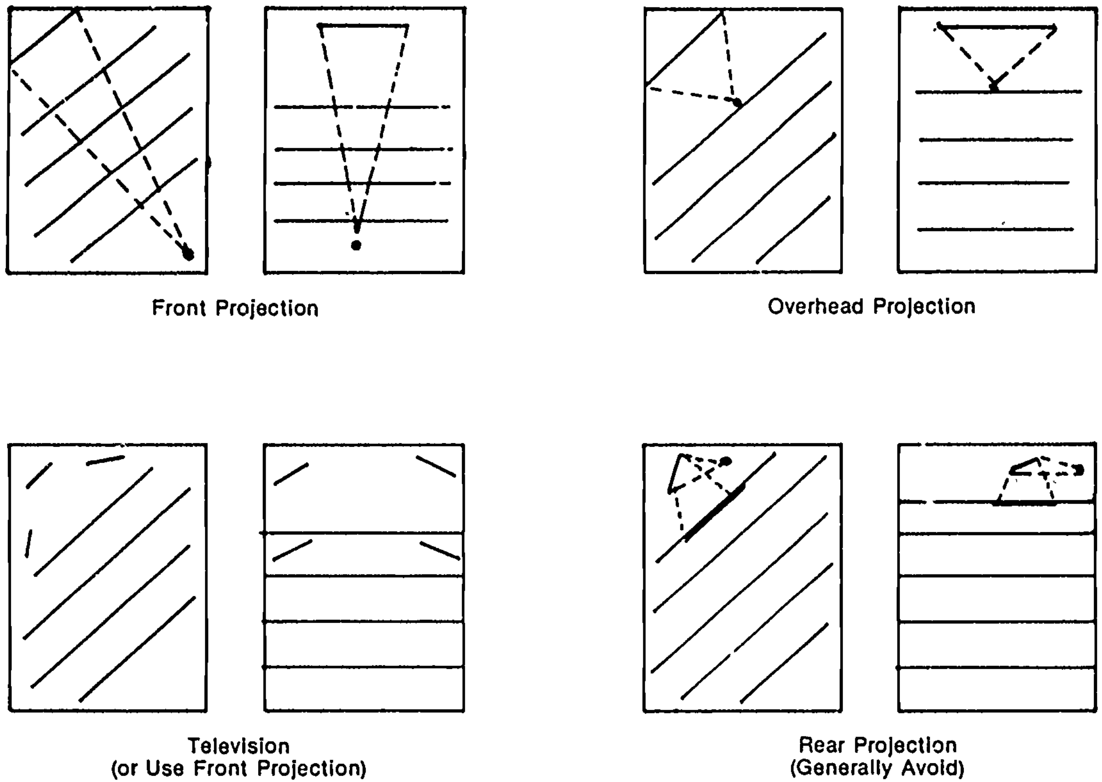

Figure 1. Classroom Space Configurations of AV Media.

Image Projection Requirements

Still visuals can be presented using an overhead projector, slide projector, filmstrip projector, microfiche projector, or almost any motion presentation medium. Each makes some demands on the classroom. All projectors require a screen at the front or in a front corner of the classroom. Most projectors require room darkening capability. An overhead projector does not require much darkening, but does require an electrical outlet at the front of the classroom, or better, centered in the floor some 10 feet from the front wall of the classroom. Most other projectors require an electrical outlet at the rear of the classroom. Since both the teacher's and the students' viewing angles prohibit viewing at extreme angles, the front corners of classrooms are typically poorly used spaces. Teachers may wish to make a corner the "front" of the classroom and place their desks and projection screen at this location. Marking boards may then be used on the two adjacent walls. When this is done, rooms may be arranged as shown in Figure 1.

A learner can perceive an object over a visual field of up to 200°, but usually a learner focuses in a cone of 30°, 15° to either side of center focus. To occupy the full 30° visual field, a visual display should be located at a distance from the eye equal to twice the width of the display.

The use of projected media requires classrooms that can be darkened; thus draperies or shades are needed in rooms with windows. It is preferable to have the screen area darkened yet have some light at the students' desks so they may take or modify their notes. In a typical rectangular room (see Figure 1) a screen should be positioned at the front of the classroom and an electrical outlet should be provided opposite the screen at the rear of the classroom. If the "front" of the classroom is located in a corner, then the electrical outlets must be provided in the opposite corner. Rear projection equipment may be placed behind the screen. Rear projection requires remote control operation of the equipment and is typically too space consuming for classroom use.

"Electronic telewriting marking boards" permit the development of an image on a marking board which "senses" where the instructor has written. This makes it possible either to produce a paper copy of the image on the board or to transmit it electronically to distant locations. In either case these boards require an electrical outlet. The electronic transmission version also requires a telephone jack. Telewriting usually requires two telephone lines so an oral presentation can also be made to the students.

The original slate blackboard has almost disappeared. Now "painted" chalkboards come in various colors but black and other dark colors are preferred by most instructors so colored chalk can be used. Dry marking boards are a logical alternative to the blackboard. These boards use erasable felt-tipped markers. The boards typically are white, or a light color, to permit the use of the markers designed for this application. Computer disk drives are easily damaged by chalk dust, so these dust free boards should be used in areas where there are computers.

Motion images can be projected by film projectors, VCR record/playback devices, or videodisk playback units. If the images from these devices are projected, they have the same space, darkening, and electrical requirements as the still motion projectors discussed above. Television images may be shown using "video display projectors," but the alignment of these projectors is quite sensitive, so this equipment is usually permanently installed on a desk near the center of the room or in the ceiling. This requires electrical power at the selected location. Television images may also be shown on monitors. The preferred locations of the monitors is also shown in Figure 1. Electrical outlets should be located on the wall near the expected monitor locations. TV monitors have relatively small screens so that students must be fairly close to them to read printed material. With this limited viewing range two or more screens are required if students are expected to see detailed visuals or read from the screen. Subdued light levels are desirable and glare on the monitor must be avoided.

In general, audiovisual equipment should be portable, but if some equipment is frequently used, e.g., overhead projectors or instructional television (ITV) equipment, it should be built into the classroom and secured in such a way that it may be readily used. AV equipment that must be checked out of a storeroom, set up, taken down, and returned to the storeroom will greatly reduce the use of the equipment by an instructor.

Distribution Systems and Conduit Requirements

Many schools today are designed so that all motion visuals can be shown on a campus-wide videotape distribution. In these cases, in addition to the electrical and darkening requirements discussed above, conduit for the electronic distribution system must have terminals at those locations where the projectors or monitors are to be located. In order to provide low cost future flexibility, conduit should be terminated at various locations in each classroom. In addition, some communication system should be available in each classroom so the instructor can request the starting, replay, holding, or termination of the distributed information.

Audio stimuli may be presented using audiotape recorders, record players, or motion visual media such as motion picture films, instructional television, computer-assisted instruction, or interactive videodisk presentations. Audio-only amplification equipment is more frequently used today for individualized instruction, often as part of a slide-tape presentation, than as a part of classroom presentations. In any event, the power requirements of this equipment should be conveniently located so that the hazard of extension cords can be avoided.

Amplified sounds easily disturb learners in adjacent classrooms and should be controlled. Sound is best controlled by designing special acoustically controlled "classrooms" or by using individual headphones. If amplifiers are used in conventional classrooms, teachers should consider closing their doors and windows for the duration of the presentation.

Audio information can be transmitted long distances to students by telephone lines, satellite or radio. Telephone lines and other "low grade" paired wire systems permit telecommunications. Telelecturing is a relatively inexpensive method for providing audio stimuli to students in different locations.

Teletext uses broadcast television systems to send information to television monitors. Teletext information systems permit school television viewers to select news headlines, sports scores, or other types of information on demand. A major limitation of teletext is that there is no feedback loop. It is thus a good reference resource but a poor instructional medium. Electrical and television access is essential.

Videotext involves sending information from a central computer using telephone lines. A user can select what information to view and control the display of information on the local computer terminal. Access to electricity and telephone lines is required.

The distribution of any instructional message can be done by: (1) a teacher or messenger physically telling someone something; (2) mailing or physically transmitting a mediated message; or (3) electronically transmitting a message. Each of these instructional distribution systems has advantages and disadvantages. An individual teacher can transmit a message orally as in a lecture, speech, or talk. This method of transmitting information is limited to a single site and usually a small audience. It is not stored and is thus neither easily analyzed nor formally revised for later presentations. It requires a minimum amount of time to prepare (a lesson plan or an extemporaneous presentation) and is relatively inexpensive (for a one-time presentation or class).

Prerecorded instructional presentations or messages can be transmitted physically (by courier or mail) or electronically. The materials may be transferred using an ITV cassette or reel, a book or manual, or computer disk. Prerecorded materials are more expensive than oral presentations as they are typically scripted and may take a hundred hours or more per presentation hour to prepare. These prerecorded media require cameras or recorders or printing presses to store the material for transmission and often projectors or playback devices for the students/readers to "view" the materials. Thus the cost per student of using prerecorded materials for a few learners (transmitted either electronically or by messenger) is very high. Another consideration: physically distributing prerecorded materials usually takes longer than electronic distribution, but may be less expensive (especially if the students pick up their own materials) than electronic distribution systems.

If possible, conduit for electrical and media distribution requirements should be provided during the design and construction of schools to reduce costs and eliminate the need for expensive and frequently unsightly modifications to instructional facilities at a later date.

The use of instructional media requires 120 volt outlets at the back of classrooms for motion picture film projectors and slide projectors. Overhead projectors require outlets near the front of the classroom or built into the floor 10 feet or so (depending on the size of the classroom) from the front wall. If the students are going to have equipment at their desks, provisions for electricity should be built into the floors or desks or be otherwise provided.

If instructional displays (computer terminals, ITV displays) or feedback units are to be situated at students' desks, it is desirable to have conduit terminating at many locations in the instructional areas to permit the required wiring to be pulled through them.

Another use of computers for instruction involves asynchronous computer conferencing (ACC). ACC permits a student to dial into a computer. Many students can talk to each other and/or their instructor from their divergent locations at home or in school via computer terminals. Students in industry (DEC and IBM) and in the military (Army Quartermaster School and the Air Force Academy) currently access instructional information in this manner. Air Force Academy instructors use computers to generate lesson outlines and graphic images. The system then allows them to present images to students via video projectors or monitors. Students who are absent, or those who wish to review an instructor's outline, notes, and graphics, may then access files at any time after the materials have been prepared.

In summary, the use of audiovisual media in schools poses several problems. Video or film projectors require room darkening capability. Projection bulbs and amplifiers produce heat, which requires a ventilation system. Audio amplified sound requires sound-deadening capacity. Electrical and communications requirements can be met by designing and providing conduit and connectors throughout the building. In most instances where projectors are used, the windows (if any) will be closed and blinds or drapes drawn to keep out light. Air flow and air cooling must be over-engineered to optimize learning under these conditions. A 500-watt lamp in a projector, for example, gives off as much heat as five people, so additional ventilation must be designed into areas where media will be used. In a television or film studio, lights also produce a great deal of heat which must also be removed. Simply providing bigger and more powerful fans is not the answer because the noise from these vents will be picked up by sound recording equipment. Baffling in oversized air ducts may be required in these facilities.

Viewing Angles and Projection Screens

Individuals can sit within an area extending 45 degrees from a *tube-type screen* (television or computer screen). The desired distance ranges between 5 and 14 times the width of the screen. Generally, the bottom of the projection screen should be 48 inches from the floor in a classroom to permit unobstructed viewing.

Students viewing a *reflected screen* (used for films, slides, and transparencies) should sit in an area within 50° (40° if possible) on either side of the center of the screen. The viewing distance from the screen ranges from twice the width of the screen to eight times the width of the screen. Try to avoid the extreme ranges if possible. The bottom of the screen should be 48 inches from the floor and to within 6 inches of the ceiling.

Classroom *projection screens* are built of different materials. Choose the one which is best for a given situation. Matte screens are smooth screens which reflect light fairly evenly in all directions. The viewing area is the widest (to 45° from a line extending from the front of the screen) for any screen. Matte screens are best for close-up image sharpness. A smooth white plaster wall with a white flat finish makes an excellent matte screen. A lenticular screen has a small lens shaped (corduroy) surface embossed on it which is brighter than a matte screen because it has a more directional light reflection pattern. The brightness is increased by narrowing the viewing area. Thus, a long narrow classroom with a low-wattage projector would be an ideal situation for a lenticular screen. The glass beaded screen (small glass beads are embedded in a white paste on a white background) is even more directional than the lenticular screen so the viewing area is even more limited. Many long, narrow auditoriums have beaded screens to improve the brightness of the images.

Rear projection screens permit lecturing and demonstrating concurrently with media projection without obstructing the image on the screen by instructor shadows. The projection equipment is usually located in a room to the rear of the students, thus requiring an equipment operator, but this arrangement keeps projector noise from disrupting students. Image quality is not as good with rear projection as with front projection. Many educators feel that rear screens do not make effective use of space and thus feel that their use is limited to executive, as opposed to instructional, presentations where requirements for additional space and personnel are not as important as the "feeling" or affect resulting from the presentation. Figure 1, above, summarizes the desired location of projection screens in relation to projectors and students.

Media and Materials Storage Requirements

A major dilemma in securing training materials lies in the knowledge that media must be readily available to instructors if they are going to be used. On the other hand, projectors and recorders which are not secured tend to disappear. The problem is how to secure the equipment in a classroom, or near a classroom, where it is convenient to the instructor.

The three most important environmental considerations which affect the longevity of *instructional materials* are temperature, humidity, and dust. In order to increase the life expectancy of film- or magnetic tape-based materials, it is important to keep them as dust free as possible, keep the temperature at or near 65°F (18°C), and the humidity at or a little below 50%. These same conditions are also desirable for equipment storage and operation.

Color films and books have a greater life expectancy as the temperature approaches 32°F (0°C). As the temperature increases, cellulose film becomes brittle, acids in books destroy the paper, colors rapidly change, and polyester tapes begin to shrink. High humidity encourages fungal growth on films, and tapes become abrasive and promote excessive head wear. As the humidity decreases below 50%, film becomes brittle and curls, and electrostatic charges on magnetic tapes increase the noise.

Audiovisual equipment (projectors, playback units, amplifiers, monitors, screens, etc.) should be stored in medium to low humidity areas to reduce oxidation or rusting of the metal cabinets and to protect electronic circuits. Sudden extremes of heat or jarring (e.g., dropping) can break the delicate lens and electronic systems.

Humidifiers or dehumidifiers can be employed to maintain the desired humidity level while air conditioning can cool the storage area. Windows in audiovisual storage areas are undesirable from a heat and light control standpoint, as well as security, and should be eliminated as far as is practically possible. The ultraviolet rays will affect the colors of your materials and deteriorate the carpeting, drapes, etc. The infrared rays will create the heat related problems discussed above.

Dustproof containers are recommended for storage of most materials. Books, films, records and tapes should be stored vertically. Magnetic tapes should be stored away from any possible magnetic fields, such as fluorescent light transformers. All materials should be stored away from heating units.

Secure storage requirements for materials are necessary. Guidelines for space requirements for AV materials are found in Table 1.

Table 1. Materials Storage Requirements

Media	Storage Requirements (# per Cubic Foot)
35 mm slides	530 slides
Film strips	160 cartridges
16 mm films (400 ft reels)	9 reels
Videodisks	38 disks
Microfilm, 35 mm	35 films
Microfiche	1,785 cards
Overhead projection transparencies	64 transparencies
Audiocassettes	143 cassettes
7" reels audiotapes	42 tapes
Long playing records	40 records

GROUPED AND INDIVIDUALIZED LEARNING ENVIRONMENTS

Grouped Instruction

Grouped instruction has been an economical way of providing instruction to large numbers of learners. Centuries ago, Plato taught students in groups as a way of increasing his tutoring income. This is still the major educational organizational pattern of providing education around the world. The grouping of students for instruction is not considered the best way to teach students, but it is widely thought to be the most cost-effective manner in which to provide instruction to a large number of relatively homogeneous students. In the past half century, a wide variety of instructional media have been made possible due to the innovations in the fields of electricity, photography, electronics and computers. Through the use of technology we can and do provide more effective and efficient instruction today than Plato could ever possibly have provided.

Open, flexible spaces are generally desirable to meet current and future requirements easily. In many cases, fixed walls will restrict the degree of flexibility. A general rule involving the design of any instructional area is:

"Form Should Follow Function!"

Classroom instruction requires lecture or conference areas for 25 to 150 students. The typical 25- to 45-student classroom is often modularized using a 30-foot long structural span stretching from a corridor to an exterior wall. The amount of space is determined by providing each of the projected students with a 2- by 3-foot area.

Student viewing of the instructor and media presentation is a primary consideration when developing these spaces. Classrooms for fewer than 50 students which require screen projection media will not require sloped floors or risers for seating. Classrooms primarily for object demonstrations of procedures or techniques and equipment for dialogue between instructors and students normally will require a riser system. The number of seats per row, the lecture platform height, and the height of the demonstration will determine the respective heights of the risers.

A 25- by 30-foot classroom with 10-foot ceilings is typical for 24 students. Seating in four rows of six students each generally will permit each student to watch an instructor presentation or view projected media presentations.

Individualized Instruction

Individualized instruction and/or self-paced instruction using instructional media typically requires approximately 4- by 4-foot or larger student stations. If audiovisual aids, other than paper materials, are not used, 4- by 3-foot carrels may suffice. Associated spaces for storage, the circulation of

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materials, and storage of equipment and materials, may require an additional 200 square feet.

Carrels should be arranged to reduce learner distractions as students and instructors move about the facility. Audio amplified equipment (motion picture projectors, tape recorders, etc.) should be equipped for individual headsets. These carrels may be backed-up to each other or placed side-by-side if access to required electrical and communications outlets is still possible. The lighting in the general area needs only 30 foot candles (fc) but the individual task areas require 70 fc.

Seminar Areas

Special arrangements for small group discussions for three to 12 students who can see and interact with each other are desirable. These seminar rooms should be in a circle, or a nearly circular pattern. The room thus will often be square with an approximately 8-foot table near its center. These smaller sized rooms result in greater individual participation than would occur in a larger classroom. The size will allow individuals to talk effortlessly without raising their voices, to easily access materials across the table, and to observe nuances in facial expressions. The lighting levels are, thus, generally high, about 70 fc. The seminar room should have complete conduit termination to permit electrical power as well as any available TV programming (e.g., to analyze previously recorded individual behaviors or review complex materials originally presented elsewhere), computer terminals (for statistical processing, access to administrative information, to review CAI materials, etc.), or other electronically disseminated information.

Laboratories

Laboratory classrooms are dedicated spaces—dedicated to the equipment requirements of the lab. These labs are used for "hands-on" psychomotor training involving small or portable equipment. Usually a lab is designed for individual, paired, or team training. There may be no instructor station, other than a place for paperwork and personal effects. Student stations will be laid out according to the type of material/hardware they will be learning to use or to maintain. In most cases there will be some kind of workspace for the students to work with the equipment and/or to read their lab manuals or job aids or to take notes upon.

Utilities should be planned according to equipment requirements. In order to upgrade the equipment, it is desirable to install many and flexible conduit outlets for electrical and communications purposes when constructing the building.

The labs will normally have 10-foot ceilings and require 30 to 60 square feet per student. When heating the area a temperature of 70°F, and when cooling, a goal of 78°F, are usually satisfactory within a relative humidity range of 30% to 70% and 10 cubic feet per minute of outside air per person. Lighting levels of 70 fc are usually adequate with 30 fc available during audiovisual presentations.

Instructor Preparation Areas

Relatively private areas are needed for the instructor to store reference materials, student papers, instructor guides, etc. Many instructors have access to this type of area only at their homes. Some school districts provide adequate preparation areas. The instructor should be able to do private counseling with students or other instructors. Three sided, shoulder height partitions may provide the needed privacy. Secure areas are needed for testing materials. Conduits for word-processing, electronic mail and electricity for each area are needed. A sound-isolated area is also desirable for printers. An area of 90 square feet per instructor would be adequate for shelving, storage cabinets, storage closets, etc., and is a desired design goal.

LIGHT AND COLOR CONSIDERATIONS

Lighting is an important aspect of any classroom. A good lighting system should ensure optimal luminous conditions for learner productivity at the various required classroom tasks. In general, research indicates that insufficient illumination, glare, reflectance, shadows, low brightness contrast, and flickering affect human performance and can be controlled by good lighting and color decisions. The overall classroom environment should be visually interesting and support the comfort, health and safety needs of the student (Sinofsky & Knirk, 1981).

Measurable increases in learning have been found by simply changing light levels or contrast, the dominant color(s) of the learning environment, or the light source.

Light Level and Contrast

Light levels should be related to the viewing difficulty of the task. While 50 to 75 foot-candles are required of a conventional classroom or study carrel to permit reading and desk-work, a drafting room or shop area needs 60 to over 100 fc. Gymnasiums and group seminar or discussion areas need only 30 fc. Reading good print in a library requires 30 fc while small print, handwriting, or photocopies require up to 75 fc. Areas with CRT (computer screens) should have 30 to 100 fc depending on the readability of the associated materials. Corridors, stairs, and elevators require 20 fc.

Demonstration areas or chalkboard areas require more light than the surrounding area to draw attention to relevant stimuli. This light level can be provided by spotlights or other directed lights. Study carrels should have light-colored finishes which will reflect a larger percentage of light onto the working surface in the carrel. Low light levels, which are required for such activities as slide viewing, should be attainable by dimming controls to allow relatively low light for note taking without affecting the quality of viewing and teacher supervision. Room lights should be located more than 50° above eye level so as not to be distracting. For more specific light levels for various types of learning activities see Knirk (1979, p. 91), or the *General Electric Lighting Level Guide* (General Electric, 1986). Note that some of the light levels in the 1979 reference are somewhat higher than those suggested above.

Light levels and colors affect individuals differently, but there do appear to be some generalities which are useful as guidelines. Dunn (1985) found that individual student reactions to "bright" and "dim" light could result in extreme negativism. She also concluded that fidgety youngsters should be placed in softly lit areas while listless unresponsive students should be placed in brightly lighted areas. The desired light level depends on the type of task. A task requiring the perception of details needs relatively more light than do tasks not requiring the same degree of visual acuity. Thus, a home economics sewing area or a machine shop requires more light than a general classroom or library, and these areas require more light than a lunchroom or locker room.

Human factors engineers often disagree as to the most desirable light or brightness level for a particular function or task. Nevertheless, the ranges of light levels suggested in Table 2 seem to reflect good guidelines.

Table 2. Minimum Light Requirements for Learning Spaces

Task	Foot Candles of Light
Corridors, stairs, elevators	20—30
Seminar rooms	30—50
Library	30—75
General classroom (at desk top)	50—75
Sewing room, lab, shop, drafting areas requiring detail work	60—100

It is desirable to avoid light levels in excess of 70 fc if rear screen projection (microfiche projectors, film projectors) are to be used. Light levels in excess of this maximum will wash the image from the screen and the image will not be visible.

Room ambient light levels in areas where visuals are being shown should be between 10% and 33% of the screen or tube brightness. Ambient light levels for 16 mm film should be between 5 fc and 10 fc if possible. Room light levels for 35 mm slides can be higher, from 15 fc to 25 fc. The ambient light levels in a classroom where students are watching ITV can be from 35 fc to 40 fc depending on student writing or note-taking tasks.

Extreme *light level contrasts* must be avoided. Thirty-five seconds at a minimum are required for partial adaptation when moving from a dark to lighted area. When moving from light (outdoor light levels may range from 2,000 fc to 5,000 fc) to dark, however, minimal adaptation requires a minimum of two minutes and up to half an hour for total adaptation. While the light ranges within a classroom will not involve these extremes, it does require some time for an individual to adapt from work surfaces or spaces having varying light levels. Constant adaptation, as from extremely dark nonreflective desk surfaces to a glossy white page of text and/or a VDT screen, can cause eyestrain and headaches.

General guidelines for task-background illumination levels suggest that the paper, book, or VDT task confronting a student can be up to three times as bright as the surrounding environment. This keeps the learner's attention focused on the tasks and provides for optimum contour and depth perception. In no case should the task illumination level exceed 10 times the general lighting level. Lighting fixtures should be designed to minimize glare and prevent light from shining directly into a learner's eyes. This can be done by placing light fixtures so the main light on a work surface is between 30° and 60° from the horizontal plane.

For flexibility in the use of modular learning spaces, *lighting controls* for each 750 square feet of space should be located near entry doors at a height that can be reached by individuals in wheelchairs. In addition, separate lighting controls to reduce the light near any projection screens should be located near visual projection equipment. It is often desirable to provide lighting at student desks while darkening the screen sufficiently to view slides, films or view-graphs. It is also desirable to have dimming controls on lights to obtain the optimal light levels.

Special lighting for TV in an instructional area will not be required if the color temperature built into the lighting systems is around 3400° Kelvin, the optimal color camera response range. This may be done by the architect or others who determine what sources of lighting and lighting fixtures should be built into the instructional areas.

Studies show that increasing levels of illumination result in smaller and smaller improvements in performance (McCormick and Sanders, 1982, p. 283). Schools, it appears, can reduce energy consumption to the lower end of the levels suggested in Table 2.

The amount of light on the page of a book should be no more than four times brighter to the viewer than the light reflected from the surrounding desk area and flooring. It is for this reason that dark desk surfaces of the past have been replaced by lighter surfaces today. A higher reflectance from ceilings is acceptable to "bounce" the light down to the reader, in part because the ceiling is not normally in the reader's line of sight. Desired ranges of reflectances for school lighting seem to be: ceilings, 70%-90%; walls, 40%-60%; floors, 30%-50%; and desk tops, 35%-50% (Judd, 1979, p. 674).

Contrast is directly related to total brightness. The brighter an instructional area the higher the possibility of having a high brightness ratio. If a student is confronted with a high contrast level, the pupils of the eyes must continually attempt to adapt to variation in light level. Learning environments should be designed so that the student, when looking up from his or her work, should be confronted with no more than 10 times the brightness of the work A student who is attempting to read in moving shadows of leaves on a tree, or who is attempting to read white pages on a dark desk top will probably soon complain about a headache or that his/her eyes hurt. Furniture manufacturers are aware of these problems, and thus for the last several years most classroom desks have been available with light colored tops. Many school and business educators or trainers seem to prefer the feeling of "oak" and dark furniture, but dark finishes are usually undesirable.

A study of noise levels in high and low levels of illumination in university hallways found that the mean noise level in the high-illumination condition (20 large overhead fluorescent light panels lit) was 61.1 decibels, while under the low illumination (two-thirds of the panels were turned off), noise levels were only 50.3 dB (Sanders, Gustanski, & Lawton, 1980). Here then, it appears, may be a silver lining in the energy crisis cloud when teachers reduce the amount of available light—peace and quiet.

Brightness may be used to direct learner attention. In a study involving deaf children, it was found that brightness patterns can significantly increase student attention to visual aids (Herron & LaGiusa, 1975). Although general lighting levels in the three schools used in the research varied, a 4:1 luminance increase on the instructional aids was attained by adjusting the proximity of lamps or spotlights to the targets. Without exception, whenever a visual learning task was presented with supplemental highlighting, attending behavior was significantly superior to that during the control presentations using general lighting alone. The light in the teaching/learning environment should be arranged so that it falls where it is needed.

According to research by Hellman (1982, p. 24), "Light has a profound effect on our immune system and may one day be used to prevent immune reactions that we don't want (graft rejection for example, or the body's response to poison ivy)....By using artificial light to lengthen the day, they are able to fool chickens' hormonal systems into thinking it is spring, thereby increasing egg production." The human hormonal system responds to light, but the human threshold is apparently higher than that of most animals. Hughes (1981) reviewed the effects of light on the human organism and concluded that sunlight-simulating environmental lighting in schools will result in greater student and teacher comfort, health, and increased performance capacity.

Color

Understanding the impact or importance of color in training is difficult, and understanding what color is and how it is generated/perceived is even more difficult. "Colour depends not only on the stimulus wavelengths and intensities, but also on differences of intensity between regions, and whether the patterns are accepted as representing objects" (Gregory, 1978, p. 127). The perception of color involves high-level processes. The color brown, for example, "requires contrast, pattern, and preferably interpretation of areas of light as surfaces of objects (such as wood) before it is seen, and yet in normal life brown is one of the most common colours" (Gregory, 1978, p. 127).

At high levels of learning, such as those found in classrooms, the rods and cones both function (photopic vision) and the learner is most sensitive to light wavelengths of about 550 nanometers/millimicrons or green colors. At decreased light levels, as found in night simulators, the cones cease to function (scotopic vision) and the eye becomes most sensitive to wavelengths of about 500 nm or blue-green (McCormick & Sanders, 1982, p. 370). It is difficult to describe a particular color considering the variables: hue, saturation, and lightness. Some color systems use color plates or chips as standards (Munsel, Ostwald) and others provide for designating colors in terms of their relative percentages of the three primary colors of light (CIE color system).

Color not only affects learning, it affects our ability to differentiate between objects, and color preferences seem to affect a learner's attention span. It seems that it would be possible to determine a student's color preference, and then use it in the learning environment (paper, desk top), to lengthen his or her attention span (Phillips, 1965). Color is, however, not essential for learning; a great many successful individuals (8% to 10% of men) are color-blind.

In general, color can affect a learner's sense of time. Red lights tend to cause an individual to overestimate time, while green or blue colors cause an individual to underestimate time. It is not known why colors affect individuals in this manner. However, given these coloring influences, cool hues seem to be more appropriate for learning tasks where routine, monotonous tasks are performed. The average classroom could benefit from relaxing pastel colors like peach, rose, light blues, or sea foam green. Use warm hues for the cafeteria and other areas when it is desirable to have the students feel that time is passing rapidly.

Color can also change perception of size. Painting the walls of a small classroom in lighter colors will make the room appear larger (Mehrabian, 1976). Long corridors can be "shortened" by painting doors and spaces in the hallway in a bright though dark tone, with a lighter contrasting tone on wall spaces between. Another way to "shorten" a long classroom or corridor is to paint the ends with a lighter, brighter accent color (Knirk, 1979).

Intense hues (e.g., dark reds and blues) tend to cause restlessness and eyestrain when applied to a large area like a classroom. Soothing neutral colors are suitable for classrooms which are occupied for long periods. Warm colors can be used in cafeterias. Cool colors help dignify an assembly hall or other large communal spaces. Vivid colors in corridors and stairwells will stimulate the students to keep moving; as the hues are not dwelt upon, they do not become oppressive (Varley, 1980).

In Table 3 note a list of colors which seem to match particular types of learner activities.

Table 3. Colors and Learner Activity

Social areas: arousing hues (which will also shorten time)

Primary classrooms: tints of red, blue, yellow

Secondary classrooms/labs (requiring close visual and mental tasks): blue-green, green, gray, or beige

Dining areas: peach, pink, turquoise (brighter if time requirements are brief)

Gyms: cool or neutral tones (to reduce distractions and attention to increased body heat)

Auditoriums: green, aqua, peach

Large pieces of equipment: paint same color as background (to reduce their distractive impact)

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The impact of color on space can be dramatic:

> Space can be further broken down into "extensive" elements (walls, floors, doors, ceilings) and "linear" elements (beams, pipes). The tendency has been to camouflage the linear elements, to paint them into the background; but more recently, successful attempts to accent these elements have brightened up many functional areas. Blue piping or a bright red radiator cease to be ugly accessories and become interesting forms in their own right. As for light, the more the better is a common notion for working areas. But glare and dazzle can ruin as many eyes as insufficient light; and now that paints have reached the point where their reflectance levels are numbered to assist the buyer, there is no excuse. A pleasant pastel with good reflectance is often less fatiguing than plain white, while in dull environs a high reflective paint can increase light levels by a third. (Varley, 1980, p. 164)

It seems that color directly influences individual physiology as measured by blood pressure, respiratory rate and reaction time (McCormick & Sanders, 1982, p. 534). Investigators are uncovering subtle physiological and biochemical responses of the human body to solar radiation or its artificial equivalent. Fundamental biochemical and hormonal rhythms of the body are synchronized by the daily cycle of light and dark. The rate at which normal humans excrete melatonin (a hormone synthesized by the pineal organ) is affected by the light cycle. The amount of melatonin generated affects sleep, modifies the electroencephalogram, and raises the levels of serotonin, a neurotransmitter. In addition, melatonin inhibits ovulation and modifies the secretion of other hormones from the pituitary, gonads, and adrenals (Wurtman, 1975). These findings may have a profound impact on the use of classroom lighting.

Fluorescent lighting is characterized by its flat, cold illumination which casts few shadows and no highlights. It is uniform, undramatic, cheap to run, and clean. Fluorescent lighting is replacing incandescent lighting in almost all schools. Wohlfarth and Sam (1981) found that lighting and color have a physiological effect on students when they studied multiple handicapped students aged seven to 10 to measure the behavioral and physiological impact of simple modifications to color and lighting in an existing classroom. The fluorescent lights were replaced with full-spectrum lighting, and the walls of the schoolroom were changed from orange and off-white to royal and light blue with a gray carpet instead of the orange rug. The children's mean systolic blood pressure dropped from 120 to 100, or nearly 17%. The children were also better behaved, more attentive, and less aggressive according to the teachers and independent observers. When the room was returned to its original design, the readings gradually returned to previous levels. They also found that light had the same impact on the blood pressure, pulse, and respiration rates of two blind children as on the students with normal sight. Aggressive behavior appeared to be the most changed by the treatment. Wohlfarth feels the electromagnetic energy that composes light affects one or more of the brain's neurotransmitters.

The effects of limited-spectrum lighting was markedly demonstrated with a group of first graders during the 1973-74 school year in Sarasota, Florida (Dusky, 1979). The four classrooms in the trial were windowless, and thus all lighting was artificial. Two classrooms had conventional fluorescent lamps, and two had full-spectrum lamps installed, with shields to reduce radiation at the terminals. Under the conventional lighting some first-graders demonstrated nervous fatigue, irritability, lapses of attention, and hyperactivity. Yet when full-spectrum lighting was installed, these same children settled down and paid more attention to their teachers, who reported improved overall classroom performance. Before the lighting was changed students were photographed by concealed cameras which showed them playing around, leaping from their seats, flailing their arms, and paying little attention. When these children were filmed again two and three months later, their behavior was entirely different. The children were calmer and more interested in their work. In those rooms where the lighting was not changed from standard fluorescence, there was no improvement in behavior. It appears that color has a significant influence on both teachers and students. Zentall (1986) found the use of color either early or late in a sustained attention task can normalize and quiet hyperactive children.

Color can transform space in schools. Different areas in open-plan designs can be visually unique and identifiable while retaining an overall unity when the colors conform to a single "set" of primary or auxiliary hues. Walls opposite windows can be decorated to reflect sunlight back on to the darker-toned window wall. Primary children seem to favor primary colors, but these can be positioned with neutral hues to prevent feelings of being overwhelmed.

Classroom color can sometimes be adjusted according to the direction the windows face. Warmer colors should be used in north-facing classrooms and cooler colors in classrooms facing south. A West German school made colors increasingly cooler in north-facing rooms to help children locate the points of the compass, thereby making the building part of the educational process (Varley, 1980, p. 164).

Another study illustrating the effects of color on humans was done by Bennett and Rey (1972). An environmental chamber was used in which the humidity and temperature could be strictly controlled by pumping hot or cold water through coils in the aluminum walls, and the subjects were asked to wear successively red, blue, and clear goggles. Under each color condition the wall temperatures were increased to 101°F and then decreased to 58°F. Subjects were asked to periodically rate their feelings of thermal comfort (investigators were interested at the points at which they shifted from "slightly warm" to "warm") in each color condition. Although the room color had no effect on the subjects' feelings of thermal comfort or on learning, the subjects still maintained that warmth varied as colors were changed.

A study by Berry (1961) also indicates that the choice of colors in a room can affect an individual's feeling of warmth. Berry placed subjects in a room under different colors of illumination, and, as the experimenter raised the air temperature in the room, they were asked to report when they felt too warm. No differences between colors and the point at which the subjects stated a feeling of discomfort were discovered, but the subjects still felt that the color of the room would affect their feelings of warmth.

The choice of color can affect test performance according to a study conducted at San Francisco College, which showed that comprehension and recall of difficult subject matter in school can be improved by using color rather than black and white slides. When testing the students after the slide augmented lectures, Clark (1975) found that green backgrounds were the most effective. When green slides were used test scores rose as much as 40% above exposure to black-and-white slides, and red and blue were the next best (p. 37).

A study by Chute (1980) indicates that color in instructional materials can promote learning. He found that, although using a film helped fourth- and fifth-grade students of all ability levels learn incidental information more readily, the use of color in the film affected the learning of task-relevant information differently depending on ability level. More research needs to be done on this topic.

When Reid and Miller (1980) examined the pictorial contents of biology textbooks to assess textbook readability, they found that the effects of color on the observations and interpretations of photographs varied with the child's ability. They also studied the achievement of pupils in three schools painted with different shades of color and found that light colors positively influenced pupil achievement.

Almost all financial institutions suggest their trustworthiness by choosing dark blue for their corporate identities. Dark blue appeals, perhaps, to an innate need for security among clients. It is also found in the logos of most American corporations.

Some shades of green are considered to be calming; therefore many school districts use them to reduce the restlessness of students. Schauss (1980), director of the Institute for Biosocial Research at City College in Tacoma, Washington, has found that pink reduces aggressiveness as it influences the secretion of hormones. Schauss points to evidence that the wavelength produced from a particular shade of pink affects the endocrine system and its regulatory hormones in such a way as to reduce strength and aggressive tendencies. The closest shade of pink to Baker-Miller Pink, the color used in this study, is Sears' Jamaican Pink. One fifth of the base paint should be semi-gloss while the remaining paint should have a flat latex base. This small amount of semi-gloss is said to increase the reflectance when dry. His finding was tested in the San Jose, California, jail, where it was confirmed that the pink color works in reducing hostility. Perhaps halls or entryways might give up their green appearance for pink. An instructional technologist must be able to consult with architects or the school maintenance people in order to obtain the desired learning.

In summary, the selection of paint for classroom walls or the color of paper for texts influences learner attitudes and ability. If arousal or activity or discussion is desired, select bright hues in active colors such as red, yellow, orange or rust. For calming students or inducing them to reflect or integrate information, use dull shades or quieting colors such as blues, greens, gray, or beige. In rest areas, dining areas, or auditoriums use shades of pink, peach, or turquoise.

HEATING, VENTILATION, AND AIR CONDITIONING CONSIDERATIONS

There is evidence to indicate that temperature, relative humidity, air movement, and overall air quality have an effect on learning and human performance. For example, as temperatures rise above, or fall below, ideal limits which may be as narrow as a few degrees, the body must work to heat or cool itself and study efficiency decreases, errors increase, and under extreme conditions, health is adversely affected. McCormick (1970) found that the effect of a poor heating, ventilating, and air conditioning (HVAC) system on performance is also entwined with such related factors as the type and duration of task, the degree of accommodation, and the level of training.

Air conditioned schools, as well as homes and offices, are of concern to researchers today because of health problems associated with airborne micro-organisms and their effects, e.g., Legionnaire's disease and humidifier fever (Hedge, 1987). Air conditioning and humidity levels are often, without consistent research, blamed for headaches, lethargy, nausea, eye problems, and nose and throat problems. In any event, humidification systems provide excellent breeding grounds for many strains of bacteria, fungi, protozoa, and other micro-organisms.

HVAC and Student Achievement

Available research on HVAC as it relates to elementary and secondary student achievement is promising. An early study examining the effects of temperature on learning was conducted at the University of Iowa in 1962 and reported by Educational Facilities Laboratories (1971). The researchers used a specially built two-room research school with "ideal" temperature conditions using heat or air conditioning as necessary to maintain 70°-74°F at 40%-60% humidity with 20-40 feet per minute air motion in one room. The other had the best conditions the teacher could get by opening windows for cooling or adjusting a thermostat for heat, i.e., 72°-80°F with humidity from 33%-75% and 5 to 10 feet per minute air flow. After some weeks in these conditions, it was found that matched pairs of fourth grade students in the "ideal" classroom displayed greater progress in completing mazes, solving math problems, performing reasoning tasks, and in completing clerical tasks than their less comfortable counterparts (also see Berlowitz, Drucker, & Scarbough, 1969).

The Educational Facilities Laboratories (1971) report included a study of college students at Kansas State University which subjected them to controlled temperatures ranging in six degree increments from 62°F to 92°F with the relative humidity held constant at 45%. The students completed assignments with minimum error rates when in 80°F environment.

Another study involving matched sixth grade students, who were taught extensively by media to eliminate teacher variation, indicates that using air conditioning to eliminate high classroom temperatures increases achievement and decreases learning time (McCardle, 1966). More recently, Chan (1980) controlled for socioeconomic status variables and found that learner achievement in air-conditioned school buildings was significantly higher than achievement in non-air-conditioned school buildings. McCardle (1966) found that students in an "ideal" HVAC environment made significantly fewer errors and required less time to complete the tasks than pupils in the regular classroom.

To determine the effectiveness of a small fan on thermal comfort, eight adults were studied in an open office at 76°F, 79°F, and 82°F with 50% relative humidity. The desks were equipped with small variable speed fans. Results showed that use of the fan could allow a 3°F temperature increase while maintaining the same comfort level, or increase comfort, at temperatures of 79°F and up (VanDyke, Rohles, & Webster, 1983).

Specific data involving temperatures for various elementary and secondary learner activities are not readily available, but as a rule of thumb, consider the following air temperatures for students wearing conventional clothes when heating a school building. For sedentary classroom activities, attempt to achieve 68°F to 70°F at 30 inches above the floor for primary grade students, and 68°F to 74°F for secondary students. For vigorous activities, temperatures of 60°F seem healthful; the range extends to 70°F for less vigorous activities. An exception to this is in the swimming pool area where air temperatures of just over 80°F, with water temperatures of about 75°F is comfortable. A temperature of slightly over 75°F in the locker room is a desirable goal. When cooling a building, a practical temperature range is two or three degrees above those suggested above. The temperature between the classroom floor and the 5-foot level should not vary by more than 3°F. The American Society of Heating, Refrigerating, and Air Conditioning Engineers' charts (*ASHRAE Handbook of Fundamentals*) show that for men and women in normal winter clothing, the optimum temperature range for individuals involved in sedentary activities is 65°F to 70°F, while in the summer, the range is between 68°F and 73°F. In studying students between the ages of 8 and 11, Harner (1973) found a significant decrease in reading speed and comprehension when classroom temperatures rose moderately above 77°F. This later study seems to conflict with other studies in that the identified temperature seems unusually high, but another study found that the performance of simple mental addition tasks can be improved by head temperature manipulation (Hancock, 1983). Using a temperature-controlled helmet inducing a 1.01°C rise in head temperature, as measured in the deep auditory meatus, results in more addition tasks performed than in a nonheating condition with no significant effect on error rate.

A study by Gilliand (1968), which involved over 10,000 temperature readings from a wide range of classrooms, found that 44% of all classroom temperatures were above 75°F. He suggested that this might be caused by the fact that the older teachers, who desire higher temperatures, have control of the thermostat. If possible, the teacher should be encouraged to wear a jacket or sweater and reduce the temperature to the levels indicated in Table 4. Gilliand suggested that for every degree centigrade of room temperature rise above the optimal level, a student's learning ability will be reduced about

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2%. In the 20 years since this assertion was made, few studies have been done to confirm or refute it.

Most of the research on adult learner achievement has been performed by the the National Aeronautics and Space Administration (NASA) and by industry studying adverse conditions. Due to lower metabolic rates, adults prefer warmer temperatures than children do; teachers should take note, and set classroom temperatures for their younger students and wear a sweater or jacket to become comfortable themselves. Women also seem to want temperatures a degree or two higher than male adults do. Adult classroom temperatures of 60°F to 70°F for such vigorous activities as those in shops seem desirable, while 68°-78°F for sedentary classroom activity seem to be desirable goals. These temperatures are valid for humidity ranges between 30% and 70%.

Given the limited studies above and the fact that there are individual differences, some general conclusions about the desired temperature ranges for instructional areas are suggested in Table 4.

Table 4. Ideal Temperatures for Student Activities

Learner/Activity	Ideal Temperature
Elementary students/general classroom	68°-70°F (30" above floor)
Secondary students/general classroom	70°-74°F
All students/gym, physical activities	(several degrees lower than above)
College/adult students in classrooms	70°-78°F

As individuals become older their metabolic rates become lower. A young child has a relatively high metabolism and is much more comfortable at a lower temperature than is an older individual. There is a positive relationship of temperature with age. This problem becomes acute with the aged. In a notice issued in the winter of 1978, the American National Institute of Aging said that, "If you are over 65, keep the temperature up to 65°; over 75, keep it over 70°. Leave energy conservation to someone else."

Humidity determines the evaporation rate at a given air temperature and this affects the learner by controlling skin evaporation and thus the apparent temperature. The higher the humidity, the less heat the body can dissipate through perspiration. Humidity levels above 70% can impair human performance and will adversely affect photographic and magnetic media. Humidity lower than 30% may cause respiratory discomfort and undesirable levels of harmful static, "shocking" individuals and destroying magnetic media.

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Green (1979) studied 3,600 students in grades 1 to 8 in 11 different schools in Saskatoon, Canada, and found that students attending schools with low classroom humidity levels, between 22% and 26%, experienced nearly 13% greater illness and absenteeism than students in schools with humidity levels between 27% and 33%. Green also cautions against excessive humidity above 50% as these high levels may result in respiratory infections.

Air composition, the amount of oxygen, carbon dioxide, and airborne particles (dust, bacteria, pollen) greatly affect the comfort and safety of school occupants. Crowded conditions like those found in schools quickly degrade air quality. Thus, it is important to consider air flow as well as the temperature in a learning environment. Air velocities of 40 feet per minute for an air-conditioned environment will be adequate while higher air velocity may be required in the summer for comfort in a non-air-conditioned facility.

HVAC and School Design

Efficient school design makes it feasible for a school district to afford effective HVAC schools. Facilities in extreme climatic conditions, such as those in the southwestern or northern United States, should be designed to minimize heating and cooling requirements. Multi-level, compact buildings which minimize heat transfer are more desirable in these conditions than the more traditional "finger-designed" schools that have more exterior wall space through which heat is easily exchanged. Even with good exterior insulation, heat gains and losses in a building are directly proportional to the area of its exterior.

A major portion of the air conditioning requirement for most school buildings results from two sources: (1) student generated heat, and (2) solar energy absorbed by building surfaces. The shading of buildings on the south and west sides by trees, canopies, and bushes can do much to reduce building cooling requirements. If these shading methods are not practical, the use of window glass is an important consideration. At a radiation angle of 40°, ordinary glass admits 85% of the solar thermal energy that strikes the glass surface, while reflective glass admits 63%. Some specialized glass will admit as low as 28%. When life-cycle costs of schools and security conditions are considered, strong arguments can be made for designing windowless schools.

In order to permit flexibility through a modular space design, each 750 square feet of space should have separate temperature controls. Since audiovisual equipment produces a lot of heat, additional controls and service may be needed in areas where they are used to remove heat from those locations without overly cooling other areas. Heat exhaust from computers is especially troublesome. See the heat discussion concerning this equipment in the computer portion of this paper.

School laboratories and shops will normally have 10-foot ceilings and require 30 to 60 square feet per student. Temperature goals of 70°F when heating these areas and 78°F when cooling them are usually satisfactory given the relative humidity considerations generally discussed above, i.e., 30% to 70% humidity and 10 cubic feet per minute per person of outside air.

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ACOUSTICAL CONSIDERATIONS

Intensity or Noise Level

The intensity of noise is measured in decibels (dB), and sound frequencies in Hertz (Hz). Noise intensity is measured on three scales: A Scale (dBA), a scale that approximates the response characteristic of the human ear (this is the sound level scale used in most of the studies in this article and is to be assumed if not specifically stated); B Scale (dBB), a scale that is intended to represent how people might respond to sounds of moderate intensity; and the C Scale (dBC), a scale that weights all frequencies almost equally.

To provide some bench-marks on existing noise levels, the author measured the following readings in and near an elementary school: office area (carpeted, A/C on, no student noises) 35dBA, 37dBB, 56dBC (aircraft and cars had the most impact on the C scale); neighborhood one block from school (quiet, no cars, airplanes, or voices in immediate area) 58 dBC; noon recess outdoors near school, 75 to 80 dBC; in an independent reading task (tiled classroom floor, 16 students, 1 teacher, 1 aide) 50 to 69 dBC with an average of 55 dBC; seatwork during math lesson, 45 to 60 dBA with average of 50 dBA, and 55 to 65 dBC with average of 60 dBC.

A relatively safe level for unprotected ears is around 135 dB. For comparison, a hair dryer makes from 60-80 dBA of noise, the music in a disco from 110-120 dBA, and sounds that cause pain occur at about 130 dB. Exposure to higher noise levels may cause a breakdown in the ear's sensitive basilar membrane and result in physiological effects such as nausea, loss of muscular coordination, and fatigue or hearing loss. While loud background noises tend to distract from the stimuli embedded in learning materials, background noise levels can be so low that the lack of noise can also be distracting. When desired audio stimuli are presented to a learner, the threshold for hearing and thus for learning, rises as the background noise level rises. The masking effect of background noise is greatest when the frequency range of the presented audio stimuli is similar to that found in the undesired background noise. The impact is also greater when the undesired noise is sudden and unexpected.

Noise levels apparently influence one's ability to learn and be healthy. Intense short-term noise of 135 dB or more may cause physiological effects such as nausea, fatigue, and a loss of muscular coordination. Continuous noise in excess of 70 dB (e.g., the din of ordinary expressway traffic) will cause, according to the U.S. Environmental Protection Agency, temporary stress reactions including increased heart rate, blood pressure, and/or blood cholesterol levels. Low intensity background noise may simply be annoying or result in distraction from desired learning tasks.

U.S. Government standards allow industrial workers to be exposed to eight hours of 90-dB noise, four hours of 95 dBA, or two hours of 100 dBA. No employee is to be exposed to continuous sound above 115 dBA.

European standards are tougher. The European Council of Ministers issued a directive on noise in May 1986. In summary, the guidelines are: If daily noise exposure exceeds 85 dBA (or the peak pressures exceed 200 pascals), adequate ear protection will be provided by employers and they are to provide their employees with hearing tests.

Noise and Achievement Research

A voice in an adjacent learning area, for example, in an open learning situation, will be less distracting if the voice is relatively continuous and at a different frequency than the voice in the primary instructional area.

The effects of background noise on performance are not all undesirable. Background music is frequently used in business to increase cognitive, affective, and psychomotor performance. The rhythm of such music seems to speed psychomotor reflexes and may build more desirable attitudes due to the screening out of unexpected and thus undesirable background sounds.

Confusion exists about which of the several descriptors of noise (A, B, or C weightings) is best related to learning achievement. Human factors specialists argue for the dBC scale. Classrooms are often found near roads and thus the background noise levels are frequently high, they argue. Traffic, particularly that containing trucks, has a spectrum showing maximum acoustical energy at frequencies below about 150 Hz. These frequencies contribute much to C-weighted noise levels but are de-emphasized in A-weighted measurements. Apparently the C-weighted descriptors of noise level are better predictors of achievement than are the A-weighted levels with younger students, and it is thought to be true of adult learners as well. "It is quite clear that for both third and sixth graders the C-weighted descriptors of noise level are more highly correlated with reading achievement than are the A-weighted levels" (Lukas, DuPree, & Swing, 1981, p. 29). The State of California suggests that a significant detrimental effect on the educational process begins when a noise level of 50 dBA is obtained, while the Federal Guidelines suggest such an effect begins at 63 dBA.

With regard to dBC, the State of California, in a federally funded program, studied 15 elementary schools in Los Angeles to determine what impact freeway noise had on third and sixth graders' learning ability in reading and mathematics. The researchers concluded that the design criterion for traffic noise levels inside classrooms should be 58 dBC, and the community noise level should not exceed 65 dBC. They found that "noise had a more systematic effect upon sixth graders than upon third graders and that noise appears to have more predictable effects upon the skills involved in reading than those in mathematics" (Lukas, DuPree, & Swing, 1981, p. 29). On an average, third graders in noisy schools were about 0.4 year behind in reading, while the sixth graders were about 0.7 year behind. The largest effects of noise were observed thus: "At a constant noise level in the community, achievement in reading decreases directly with increasing noise level in the classroom" (Lukas, DuPree, & Swing, 1981, p. 32).

It is not only the absolute value of background noise intensity that results in task avoidance and makes learning difficult, but also the total range of intensity values, predictability of the occurrence of the sound, the relationship of the frequency of sound being attended to (teacher's voice) and the frequency of the other noise source(s) which result in distraction or learning interference (Corso & Moomaw, 1982). However, "by choosing the right studies, one can show that noise produces either a decrement, no effect, or an improvement in performance" (McCormick, 1970).

> We can make a few generalizations about the effects of noise on performance. With the possible exception of some memory tasks, the level of noise required to obtain reliable performance effects is quite high, generally over 95 dBA. Performance of simple, routine tasks may show no effect and often will even show an improvement as a result of noise. The detrimental effects of noise are usually associated with difficult tasks which require high levels of perceptual or information processing capacity, or both. (McCormick, 1970)

Detrimental effects of a high noise environment include (1) increased confidence in judgment—some decision makers become more confident in the presence of noise; (2) funneling—people will typically focus their attention on the most important aspects of a task or the most probable sources of information; and (3) gaps—no opportunity for relaxation which will allow moments of low performance and gaps in performance (Broadbent, 1976).

The research on the effects of noise on achievement is fairly extensive. While studing the acoustical problems in designing primary schools, Lewis (1977) noted that background noise can inhibit communication "by preventing the whole of speech being heard above the background noise" (p. 35). No precise dB level was provided. Larson and Petersen (1978) compared the effect of 10, 15 and 20 dBA signals over the teachers' speech level (human speech ranges from about 46 to 74 dB). At +20 dB, young school children's mean score fell 17% below the mean for quiet conditions while adults' scores fell 7%. The authors concluded: "The results suggest that five- and six-year-olds should be protected from noise if they are to develop optimum listening and learning skills" (p. 265).

Noise levels greater than 70 dBA affect performance on cognitive tasks. This is especially true of tasks involving short-term memory requirements. Weinstein (1977) reports that 68 to 70 dBA noise significantly impairs performance which requires short-term memory (e.g., detection of grammatical errors while proofreading) but does not adversely affect detection of spelling errors. Salame and Wittersheim (1978) used four conditions—quiet, noise uninterrupted during the presentation of each list, noise emitted simultaneously with each list element, and noise emitted in the intervals between elements—and a task of remembering a six-digit list. At 96 dBA all noise conditions yielded more errors and omissions than the quiet condition, with the highest error rates occurring where noise was superimposed over the digits.

The effect of noise and task concentration was studied on 101 females who were asked to retrieve words beginning with particular letters that were instances of specified categories (e.g., Fruit-A). The effect of noise on memory, Smith (1982a) found, is not a uniform and mechanical exaggeration of dominance of the category instance possible, but depends on the retrieval strategies being employed by the particular student. In another experiment involving 45 females using a modified version of Hockey and Hamilton's task of memory for order and location, Smith found that one of the effects of noise was to improve performance on a primary task and impair performance on a secondary task (Smith, 1982b). The effect was due to noise interacting with task priority and not with the identity of the task performed first rather than second. Priority instructions have to be effective for there to be an interaction between noise and priority. The major effect of noise is to bias the allocation of effort toward that operation which appears to best repay the investment of more effort. This may take the form of a bias toward the high priority task, but the effect of noise also depends on the difficulty of each part of the task and the salience of the stimuli.

Johansson (1983) studied learning, reading, multiplication, and writing pressure of 65 10-year-old children for two hours under three conditions—silence, intermittent noise and continuous noise—and interaction with personality (Stroop Color-Word Test). Students with high intelligence solved more items on the multiplication task in noise than in quiet conditions. Low IQ students, however, were found to be negatively affected by the noise as measured by a multiplication test and a reading test.

A study by Pelletier (1984) explored the effects of continuous and intermittent pure tone noise at fairly low levels (70 dBA) in a task requiring a high level of cognition ("evaluation" in Blooms' taxonomy). It was found that noise conditions significantly decreased performance. An unusual finding in this study was that there was no significant difference in the continuous or intermittent sound conditions, although high frequencies (8000 Hz) were significantly more detrimental than low frequencies (500 Hz). No significant differences were found between groups when the quantity of work was examined.

Poulton (1978) contends that the known effects of noise on performance can be explained by four determinants which combine to affect performance: (1) masking of acoustic task-related cues and inner speech; (2) distraction; (3) a beneficial increase in arousal when noise is first introduced, which gradually lessens and falls below normal when the noise is first switched off; and (4) positive and negative transfer from performance in noise to performance in quiet. Positive transfer results from the better learning of the task in noise under the influence of the increase in arousal. Negative transfer results from the techniques of performance used in noisy conditions to counteract the masking or distraction when they are not appropriate in quiet conditions.

Larson and Petersen (1978) compared 40 five- and six-year-olds with 40 20- to 26-year-olds in their abilities to discriminate speech from background noise at various levels of interference. In the quiet listening condition, the discrimination of the young children was only 2% lower than for adults. When interfering noise was introduced with speech, the ability to discriminate decreased in both groups. However, the effect was more significant for the young children in that their speech discrimination scores were 17% to 20% lower than those of the adults. The author also discusses implications of open vs. self-contained classrooms. Salame (1978) exposed 20 undergraduates to continuous noise, quiet and noise emitted simultaneously with each list element, and at intervals between elements. All noise conditions yielded more errors and omissions than the quiet conditions.

Individuals may accept high noise levels, as long as they are understood and predictable. In a study by Vallet and Francois (1982) analyzing noise upon the opening of Paris-Roissy airport it was found that local residents experienced only moderate EEG response rate after one year of exposure, a sign of existing but limited habituation to noise. High levels of annoyance with the airport due to noise continued during first two years after opening, but night annoyance then decreased to reach moderate levels, as did psychophysiological disturbance.

Von Wright (1979) studied the effects of noise on three groups of 36 six-year-olds, nine-year-olds, and undergraduates, who were asked to perform speeded card-sorting tasks. Noise slowed the sorting performance of undergraduates in all conditions; it slightly improved the performance of nine-year-olds; and it improved the performance of six-year-olds significantly when irrelevant information was present. In another study, von Wright (1980) asked 70 high school students to recall the names of countries during a 5- or 8-minute period of either silence or intermittent white noise (95 dBA). Noise interfered with neurotic students but had little effect on stable students, and performance was not related to extroversion or self-rated activation. Waters (1983, p. 74) suggests that sound louder than 60 dB affects concentration and a sense of well-being. Background noise apparently interferes with learning or concentration in some learners more than with others.

I highly recommend Wheale and O'Shea (1982) as an easy to read and logical summary of the impact of noise on performance. The booklet was written in Swedish and translated into English by the Department of Labor. Many useful techniques for modifying noisy work environments are suggested.

Surviving with High Noise Levels

The effects of background noises on performance are not all undesirable. Background music is frequently used in business to increase cognitive, affective, and psychomotor performance. The rhythm of such music seems to speed psychomotor reflexes and may build more desirable attitudes by screening out unexpected and thus undesirable background sounds. The ability of students to attend to desired instructional stimuli and learn is affected by sensory stimuli in their environment. A background noise level of about 35 decibels of full-spectrum or "white noise" produces optimum alertness (Department of Army, 1976, p. 3-5).

Background music played in a classroom appears to improve the behavior of hyperactive children (Scott, 1970). A study found that background music improves student learning of "relevant" concepts (Stainback & Hallahan, 1973). Music may even improve student test scores (Hall, 1952; Whitely, 1934). The long term effect of music on learning is not known, however, because there have been no long term studies.

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Unwanted noise can be controlled in schools by use of carpeting or other soft surfaces on floors, walls, and ceilings. These can all be treated, especially if interior spaces are small. Sound bouncing from hard surface walls is as disruptive as that from ceilings. The most important treatment area on a wall is from two to six feet from the floor because that is where most of the noise is produced.

Classrooms are often noisy because educators seldom consider how to reduce the source of unwanted noise. The sudden and high pitched sound of a metal chair leg on a tile floor is one of the most distracting of sounds in a classroom. This and many other distracting sounds in a school can be eliminated with acoustical floor tiles or carpeting. Carpeting is the first line of defense in a school against potentially distracting sounds.

An instructor's voice may be reinforced in classrooms by having sound reflective surfaces on the ceiling, the wall behind the instructor, and the upper half of the side walls. The other surfaces in the classroom should be sound absorptive so that distracting reverberations and noises generated close to the floor by the dropping of objects or the scuffling of shoes and desks is reduced.

Another factor affecting acoustics and noise is the general layout of the classroom. The shape of individual workstations and the direction they face influences the direction in which sound flows. Sound travels in straight lines and in a cone-shaped fashion. Seeing the lip movement, expressions, and gestures of a person across the room increases intelligibility. Workstations should not be directly across from each other, but staggered to avoid direct sound paths. Panel components should be arranged to direct speech and other sounds into them. Techniques to ensure acoustical privacy also include enclosing or wrapping noisy equipment, especially printers.

The selection of *classroom carpeting/acoustical tiles* or other surfacing materials should be made with acoustical, safety, maintenance, and life-cycle cost requirements in mind. The use of amplified audio via tape recorders, ITV, film projectors, etc., results in the generation of noise which may be dramatically reduced by carpeting and the use of wall draperies.

Weinstein (1982) found no evidence of appreciable adaptation in self-reported noise effects, annoyance, or tendency to focus attention on the noise. Instead, students became more pessimistic about their ability to adapt to noise as time progressed.

FURNITURE AND ERGONOMIC CONSIDERATIONS

Classroom Chairs and Tables

Interior furnishings must be appropriate to the instructional activities being performed. In general, the materials should require low maintenance considering their use and life-cycle costs, and meet fire and other safety requirements.

Student chairs that are too comfortable may discourage participation and reduce alertness. On the other hand, desks should be selected that are reasonably comfortable so students are not distracted by pain. Safety considerations require rounded edges on all furnishings. Specific information on chairs and table heights, angles, and furniture designs for computers is included in the next section.

The primary objective in selecting the correct chair for a workstation is personal comfort. The correct chair needs to be adjustable; it must fit the individual in a variety of positions and for a variety of tasks. Most chairs allow for back attitude control which locks the chair into several different positions. The appropriate position balances the user's weight between the upper torso, which is supported by the chair's back, and the feet. Almost all chairs feature height control; the proper height allows the feet to rest flat on the floor while enabling the thighs and forearms to remain horizontal. Another consideration is seat depth and width. Seat depth should allow for adequate support of the thighs while adequate width stabilizes the trunk and distributes the body weight evenly. Proper seating allows the body weight to be supported primarily by the bony structures of the buttocks while reducing stress on the back and leg muscles.

Computer Furniture, Keyboards, and Furnishings

Musculoskeletal, or ergonomic, difficulties often arise because a "long period of sitting puts a strain on the back and neck, slows circulation in the legs, and generally reduces muscle tone" (Johnson, 1983, p. 2). Students need frequent breaks to compensate for the static nature of computer-based instruction. Few studies involving the best chairs and furniture for student users are available.

In studying computer workstations in 1981, State Farm Mutual Insurance Co., in Bloomington, Illinois, tested four different workstations consisting of a chair, writing surface, storage unit, and terminal stand. It was found that ergonomically designed stations increased performance by 10% to 15% (Tarter, 1983).

Ergonomics, so far, appears to address the computer terminal only as a physical tool and leaves the psychological and intellectual questions of computer software up in the air.

> We access the computer and tell it what to do through terminals. As a physical tool, terminals relate directly, at first glance, to the environment

of the typist. The keyboard and copystand of the typewriter have become the keyboard and VDT. Consequently, ergonomic standards relate mainly to the use of word processors and neglect those other business functions such as decision support systems for executives, the increasing use of electronic mail, and specialized areas, such as stock brokers. (Rudin, 1982, p. 64)

Keyboard layout can affect how rapidly students can type but there is no agreement about the relative advantage of the various "standards." Schools should consider using typewriter keyboards that will enhance the quality of their work. Norman and Fisher (1982) found that novice typists can find a letter faster with an alphabetically organized keyboard. Performance with the Dvorak keyboard, which is ergonomically engineered to reduce finger movement and use the strongest fingers, is improved only about 5% over the standard keyboard. The authors conclude that it is neither worthwhile to use alphabetic keyboards for novice typists nor to change to the Dvorak layout for experts. Lu (1983), on the other hand, says the speed improvement of the Dvorak layout compared to the standard QWERTY layout is between 5% and 25%. The reason, he says, is simple: the balance between left- and right-hand usage in QWERTY is 56/43%; Dvorak is 44/56%, and thus better suited to right-handed typists.

With the Dvorak layout more of the keystrokes are on the home row and less hand movement is required. Another problem involves the failure of the American National Standards Institute (ANSI) to include in its Dvorak and QWERTY keyboard layouts a position for the backspace key, tab key, control key, and the escape key. The better keyboard for computer-assisted instruction (CAI), training in word processing, or programming in schools is still controversial.

Chairs should allow back attitude control and lock in several different positions. The seat and back should be constructed to move as the body moves. The seat should be able to be raised or lowered several inches up or down from the average 16- to 17-inch height above the floor required by secondary age students. Many ergonomically designed chairs for adults adjust from 13 to 20 inches to accommodate the majority of the adult population. Some chairs are so adjustable that they move up and down hydraulically with very little effort. Some seat fronts lower from the standard 6° pitch to 5° in order to accommodate shorter students, and rise to 8° to suit the taller ones.

Appropriately contoured back support for developing student spines with appropriate lumbar curves is desirable. The recommended overall back support angle is between 95° and 105°. The angle combines with the lumbar curve to reduce pressure on the buttocks, which should support slightly more than half of the body weight. The balance of the weight should be divided between the upper torso, which is supported by the chair back, and the feet. The students' feet should rest comfortably on the floor.

Another important consideration in selecting chairs for computer stations is seat depth. Seat depths of less than 13 inches do not provide, on an average, adequate support under the thighs, while those greater than 16 in-

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ches will not accommodate small women. The front edge of the seat comes in contact with the back of the leg of a small woman, forcing her to sit toward the front or to slide away from the backrest support. The result is poor posture. On the other end of the scale, seat lengths of 18 inches are required for fuller thigh support and tall students.

When determining where to place the personal computers in the school there are several points to consider. Just because they are called desk-top computers does not mean they will function well on a desk. Since most desk tops are about three inches taller than the recommended typing height suggested above, it is clear that placing computers on existing desks is not preferable (Turner & Heller, 1982, p. 27).

Desks should be large enough so that at least two students can work at one computer. A good computer station should have conduit or tracks for electrical wires to keep them away from feet and chair legs.

The VDT's ideal *distance from the eye* is about 18 inches. The center of the VDT should be positioned so the user looks down at about a 25° angle. The typical secondary student typist should have the home row on the keyboard 28 inches above the floor (note that the tops of most business desks are about 30 inches above the floor) and should be seated about 18 inches above the floor in an ergonomically designed chair (Rudin, 1982, p. 64). For higher, conventional desks, it is desirable to have a computer keyboard which is not permanently attached to the computer display. The National Computer Graphics Association (Rowinsky, 1987a, p. 99) suggests more specific requirements for computer furniture: mean viewing distance from viewer to VDT should be 29.9 inches (range 24.0 in. to 36.6 in.); height to 19-inch VDT center from the floor of 40.6 inches (range 36.2 in. to 45.7 in.); height to home row of keyboard from floor 31.1 inches (range 28.0 in. to 34.3 in.); height to the viewer's eye from floor 45.2 inches (range 42.1 in. to 50.0 in.); viewing angle below horizon from eye to VDT 9° (range +2° to -26°); angle of keyboard 18°; angle of VDT display 4° (range -2° to -13°); and seat height 18.9 inches (range 16.9 in. to 22.4 in.). Height distances for younger primary age students should be scaled back from the above recommendations.

Lighting for the computer should be diffused so that there is no glare on the screen. A limit of 700 lux for ambient lighting may be reasonable if the quality of light is good (Hirsch, 1984, p. 3). Additional information on lighting is provided later.

Since the computer generates student traffic and noise it should be placed close to access points and away from quiet work areas. Consideration should be given to providing secure storage areas for computer programs. This means away from heat sources and away from any magnetic field such as a fan motor, etc. If the computer is used as a terminal for time-sharing or a databank, telephone lines to the student stations are needed.

The workstation must support the comfortable use of computer-related equipment and the efficient performance of total task requirements. A common complaint is that there is little work space to do auxiliary tasks. Electronic equipment does not do away with paper and/or pencil tasks, and the work surface must support both the primary or most frequently used equipment, and any other equipment necessary for immediate support functions. The work surface depth is determined by the total depth dimension of the largest piece of equipment with lateral and rear clearance for equipment access and ventilation or for a specific task requirement. The work surface height should be adjustable to reduce the chance of musculoskeletal fatigue and provide for a correct VDT viewing angle.

Carpeting and Flooring Materials

The selection of *classroom carpeting/acoustical tiles* or other surfacing materials should be made with acoustical, safety, maintenance, and life-cycle cost requirements in mind. The use of amplified audio via tape recorders, ITV, film projectors, etc., results in the generation of noise that may be dramatically reduced by carpeting and the use of wall draperies. The use of carpeting as a highly effective noise reducing device is also discussed in the acoustical section.

Carpeting is a versatile, flexible material available in a wide range of specifications. It upgrades the acoustical environment and maintenance costs are lower than for other floor coverings. Carpeting improves the acoustical environment by minimizing noises radiating from computer equipment and voices, from objects scraping surfaces, and from the impact of footfalls and/or objects striking the floor.

Certain carpeting materials have high static electricity potential when they are in contact with one another. PVC, oak tanned leather, and neolite are common materials used in the manufacture of shoe soles. Wool and nylon have a high static electricity potential when in contact with these materials. Carpeting must be static resistant. Static electricity is reduced when a conductive path from the body to the ground is provided for the electrical charge. One way to make carpeting electrostatically conductive is to include a carbon infused antistatic fiber for every four or five nylon fibers.

Classroom Furnishings

The permanent positioning of charts or mockups which are not relevant to the objectives being taught, or do not provide a simulated environment within which the training would be eventually used, should be avoided as they are potential distractors. Anything which might distract the learner's attention from the instructional objectives being taught should be avoided.

Windows or Window-less?

There are two common arguments for the design of windowless schools. The first involves the elimination of outside distractions from visual (airplanes, rain, or snow) or audio (playground and street noises) sources. Another common argument for windowless classrooms involves the reduction of heat transfer through the windows, i.e., heat loss in the winter and heat gain during the summer. A common argument against windowless school designs also involves HVAC requirements: if electricity is lost in a windowless building, the ventilation systems cannot operate.

Despite clear preferences by teachers for classrooms with windows it is not clear that student achievement or attitudes are helped or hindered by classrooms without windows. Research supports neither the claim that windowless classrooms allow fewer outdoor distractions, and thus promote higher achievement, nor does it support the fear that the absence of windows will have harmful psychological or physical effects on children.

In one of the best studies on this topic, Larson (1966) conducted a three-year study of kindergarten through third grade students and found no significant difference in student attitudes or learning when they were placed in windowless environments.

Since windows apparently do not affect learners, electronic classroom designers may wish to consider designing windowless classrooms for better control of temperature, light levels, and vandalism.

Personal Space Requirements

Seating position in a classroom can affect achievement. Thus student seating must be flexible instead of fixed. Students seated near windows or in the rear of a classroom are less successful in school than students seated in the "front and center" of the class area (Weinstein, 1979). It has also been found that students, when assigned to seats in the front rows, were more attentive and engaged in desired, on-task activities than were students in other rows (Schwebel & Cherlin, 1972). When teachers then randomly reassigned seats, it was evident that the students who were moved forward had the greatest mean increase in time spent on task. These students were also rated more favorably than in the past.

There have been several studies which indicate that participation seems to increase as the student sits nearer the instructor (Sommer, 1967; Adams & Biddle, 1970; Wulf, 1977), and that participation in discussions can be enhanced by arranging the seating of students into circular or horseshoe arrangements (Patterson, Kelly, Kondracki, & Wulf, 1979). This relationship between participation and distance seems to be equally true in elementary, secondary, and college classrooms. It would appear that women have a slightly greater tendency than do men to desire or need a more direct seating orientation to facilitate maximum interaction (Ellsworth & Ross, 1975; Patterson, 1978). Teachers seem to call upon students more frequently if they are seated toward the front of the classroom (Delefes & Jackson, 1972). Students who sit near the teacher appear to possess positive attitudes toward the teacher and/or toward themselves (Walberg, 1969; Morrison & Thomas, 1975). In a study by Becker, Sommer, Bee, & Oxley (1973), college students were asked to fill out a questionnaire indicating their seat, course grade, and grade point average. The results demonstrated that course grades decreased as a function of distance from the instructor both toward the rear and toward the sides. There was no significant relationship between the students' overall grade point averages and seating position.

A minimum of 16 square feet of floor space is needed for mediated in-

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struction in study carrels. A classroom for lectures requires about 12.5 square feet per student position for adults. Special areas will also be needed for administrative requirements, laboratories, storage, custodial supplies, television studios, graphics production areas, and a library or instructional materials center. As the density increases in a classroom there will tend to be dissatisfaction, nervousness, less social interaction, and increased aggression. Proxemics, the study of personal space and how individuals respond to and use distance between themselves and others, needs more research by educators. Sommer (1969) found that people follow established rules in how far apart they can comfortably stand or sit. The friendlier two people are, the closer they will be. A person stands closer to someone he or she likes or knows well. Students can "come on" to someone sexually by standing closer than usual to them, thus showing interest without having to say anything directly.

Crowding seems to produce stress. A study by Freedman (1972) assigned the 126 high school students in groups of nine to either a large room (200 square feet), a moderate room (120 square feet), or to a very small room (30 square feet). In the small room, everyone had just enough space to put his or her feet on the floor without touching anyone else; each person had a little less than four square feet of space. All of the rooms were as nearly identical as possible. They had air conditioning which could keep the room comfortable, good air flow to keep body odors at a minimum, and insulation to keep noise levels about equal; only the density of the rooms varied. The participants stayed in the rooms three hours a day for three days and worked on a wide range of tasks. In this study no effect on performance was found due to crowding. Crowding did not act as a stressor which interfered with performance on either simple or complex tasks. The researchers replicated this study a number of times with different tasks, different populations, and for different lengths of time with no effect on performance.

In a study with 22 groups of schoolchildren in large and small play areas, Loo (1972) found that the size of the room had no effect on aggressiveness. A second study by Freedman (1972) with 136 high school students found that when the students were in a competitive game situation, crowding did have a generally negative effect. There was a big difference between the reactions of groups of all males and all females. Groups of girls were somewhat less competitive in the small room than in the large room, while the boys were more competitive in the small room than in the large room.

The impact of school facility size and learning is difficult to measure. In 1959, James Conant in *The American High School Today* concluded that one way to improve schools was to reduce the number of small high schools. Consolidation of schools has occurred at a rapid pace despite the opposition of individuals who felt that local schools served local interests better. Larger schools do seem to improve the quality of education, but the research is ambivalent. It is argued that large schools can justify offering a broader range of more specialized classes with specialized staff than can smaller schools. Many research studies that support these arguments are summarized in Fonstad (1973). An Educational Research Service (1971) report, however, summarized 119 studies which prohibit making a positive statement about

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the impact of school size and quality. Studies do indicate that student participation in extracurricular activities and opportunity and motivation for participation in the life of the school are better in smaller schools (Morgan & Alwin, 1980). That larger schools are cheaper schools is also supported by a number of studies (McGuffey & Brown, 1978). The optimum range of high schools in terms of cost effectiveness is probably around 1,600 or 1,700 students (Fox, 1981; Guthrie, 1979).

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