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Maximizing Usability: The Principles of Universal Design

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The Center for Universal Design at North Carolina State University has developed a set of seven Principles of Universal Design that may be used to guide the design process, to evaluate existing or new designs, and to teach students and practitioners. This article presents preceding design guidelines and evaluation criteria, describes the process of developing the Principles, lists The Principles of Universal Design and provides examples of designs that satisfy each, and suggests future developments that would facilitate applying the Principles to assess the usability of all types of products and environments.

Key Words: Universal design—Principles of universal design—Design guidelines—Evaluation criteria—Assistive technology.

Universal design can be defined as the design of products and environments that can be used and experienced by people of all ages and abilities, to the greatest extent possible, without adaptation (Center for Accessible Housing, 1995). In the best examples, universal design features go unnoticed because they have been fully integrated into thoughtful design solutions that are used by a full spectrum of the population. Successfully designed universal solutions do not call attention to themselves as being anything more than easier for everyone to use, which is exactly what they are. Designs that were developed with consideration for the needs of a diverse population work for men and women, children and elders, small people and large, and people with temporary or longer-term disabilities. They work when it's dark, noisy, wet, or when we're tired. Everyone benefits.

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TYPES OF ACCESSIBLE DESIGN

Accessible design can be defined as design that meets prescribed code requirements for use by people with disabilities (Center for Accessible Housing, 1991). Because it is often achieved by providing separate design features for "special" user groups, it can segregate people with disabilities from the majority of users and make them feel out of place. Examples of accessible design include ramps alongside entrances with stairs; oversized paddle blade handles on large, lowered sinks in public restrooms; and auxiliary tactile signage. These solutions can be stigmatizing and costly, sometimes added on to existing designs or even to new construction at the end of the design process. When added on later, accessible features reflect the designers' failure to consider people with limitations until after the fact, often until forced to by law.

Universal design is always accessible, but because it integrates accessibility from the beginning of the design process, it is less likely to be noticeable.

Adaptable design features are modifications made to a standard design for the purpose of making the design usable for an individual, as needed (Center for Accessible Housing, 1991). Some examples of adaptable design are base cabinets that are removable from under bathroom sinks, volume controls for attaching to telephones, and large grips for adding to kitchen utensils. Like accessible designs, adaptable design features sometimes look tacked on, are stigmatizing, and add expense.

Universal design sometimes employs adaptable strategies for achieving customization, but it is best when all choices are presented equally. Examples include a height-adjustable cooktop that can move between low for short or seated cooks and

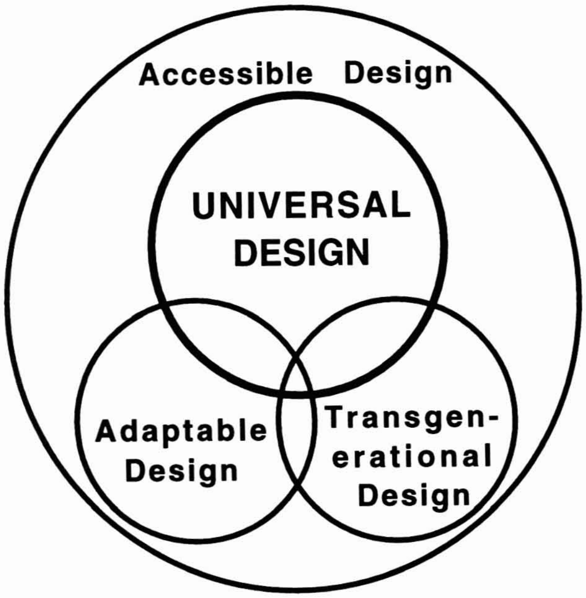

FIG. 1. Relationship between accessible, adaptable, transgenerational, and universal design.

high for tall and standing cooks, or a choice of overlays for a microwave control panel, such as braille (for those who cannot see but know braille), tactile (for those who don't know braille), or smooth (for easier cleaning if low vision is not a concern).

Transgenerational design, sometimes called lifespan design, is design that considers the changes that happen to people as they age (Pirkl, 1994). Because it does not specifically address congenital conditions or changes that may happen as a result of an injury or illness, transgenerational design does not necessarily address the full range of possible disabilities nor other factors that affect usability, such as gender differences, cultural background, and literacy level. Some universal design is transgenerational, but the approach is inclusive of more than just age-related disabilities.

Universal design, then, is sometimes adaptable and sometimes transgenerational but always accessible. The relationship between the four types of design can be illustrated as shown in Figure 1. Figure 1 shows a large circle labeled "Accessible Design." Within it are three small circles, and portions of each small circle overlap the other two; in the center, all three overlap. The three small circles are labeled "Adaptable Design," "Transgenerational Design," and "Universal Design." This diagram illustrates that universal design, adaptable design, and transgenerational design are all subsets of accessible design. Sometimes a design can be considered to be two of these subsets, and some designs are all three.

Not all accessible design is universal. Designs that fall within the relm of "accessible" but outside of "universal" exlude some users, such as a control panel with large membrane switches that suit people with limited manual control but not people who are blind. Universal design is the most inclusive and least stigmatizing of the three types of accessible design because it addresses all types of human variation and accessibility is integrated into design solutions.

HUMAN ADAPTATION

There are three ways to enhance an individual's capabilities: change the person, provide the individual with tools he or she can use, or change the environment (Vanderheiden, 1997).

The first approach requires the most of the individual. It involves surgery to change the body itself, therapy to change what the body can do, and/or training in adaptive techniques to change how the person behaves.

The second approach, providing the individual with tools he or she can use, utilizes assistive technology. Assistive technology can be defined as any device that makes it easier or possible for someone to use a product or environment or to accomplish a task that would otherwise be impossible or at least more difficult. Some assistive technologies, such as eyeglasses, hearing aids, or leg prostheses, are devices worn by individuals to help them in a general way as they go about their daily lives. Other technologies, such as magnifying glasses, sound-amplifying TV headphones, or walking canes, are tools used by individuals to accomplish specific tasks.

The third approach, changing the environment to make it easier to use, would include lowered kitchen sinks with open knee space below, tactile lettering or symbols on signage or products, and open or closed captioning on television and video programming.

These are all methods of adaptation, although the three categories above are listed in decreasing order of how much they require of the individual. The implications of the change of focus are significant and have a major impact on people's independence and self image. Universal design applies to the third approach, changing the built environment, which includes everyday products, buildings, and outdoor environments. Its goal is to minimize the need to change the individual or employ assistive technology and to make everyone's use of products and environments as smooth as possible. Universal design strives to minimize the amount of adaptation required of the individual and maximize their natural inclusion in daily activities of all kinds.

DESIGN GUIDELINES AND EVALUATION CRITERIA

How is assistive technology designed? A number of groups have published guidelines for the development of various specific technologies, most notably those contained in the Telecommunications Act of 1996 (Telecommunications Access Advisory Committee, 1997). Several references contain criteria for telephones (Francik, 1996; Pacific Bell, 1995), consumer electronic products (Electronics Industries Association & Electronic Industries Foundation, 1996), accessible Internet web sites (Vanderheiden & Lee, 1988), or computer software (Vanderheiden, 1994). Staff at Honeywell (1992) wrote some preliminary *Human Factors Design Guidelines for the Elderly and People with Disabilities* that address

- controls,
- visual displays,
- auditory displays,
- functional allocation and panel layout, and
- operating protocol.

Although incomplete, they represent one company's noteworthy attempt to serve a broader market. Vanderheiden and Vanderheiden (1992) developed a set of excellent guidelines for the design of consumer products, addressing

- output/displays,
- input/controls,
- manipulations,
- documentation, and
- safety.

They offer specific recommendations to improve the accessibility of a wide range of products.

Other published guidelines address the needs of specific groups of users, such as those published by The Lighthouse for legible text for people with low vision (Arditi, 1997a, 1997b). All of these guidelines are useful for improving the accessibility of the specific product areas addressed.

In addition, researchers have developed sets of general design evaluation criteria, most notably those developed by Batavia and Hammer (1990) for the evaluation of assistive devices. Their original 17 criteria were subsequently reviewed by the Rehabilitation Engineering Research Center (RERC) on Technology Evaluation and Transfer (RERC-TET) at the University at Buffalo, which asked consumers to evaluate the criteria and help amend them for use by the RERC-TET in their product evaluations (Lane, Usiak, & Moffatt, 1996; Lane, Usiak, Stone, & Scherer, 1997). Their resulting 11 criteria, condensed from the Batavia and Hammer criteria, are

- effectiveness,
- affordability,
- reliability,
- portability,
- durability,
- securability,
- physical security/safety,
- learnability,
- physical comfort/acceptance,
- ease of maintenance/repairability, and
- operability.

These criteria are helpful in developing and evaluating designs that address issues identified by consumers as being the most important to them when purchasing and living with assistive devices. They cover all aspects of ownership and use.

Universal design has suffered from a lack of defining criteria such as these for assistive devices. It has been communicated most often through citation of good examples of the concept rather than concrete description of its characteristics.

For example, Ronald L. Mace, founder and Program Director at The Center for Universal Design at North Carolina State University, advocates presenting a hierarchy of universal design examples, from designs requiring the least amount of interaction with users to ones requiring the most. He uses doors as an example. His hierarchy of interaction ranges from no door (just an opening in a wall) to powered doors triggered by motion detectors, sensor mats, or push buttons to nonpowered doors that must be pushed or pulled. Doors with no latch are easier to open than ones with lever door handles, which are easier than ones with round doorknobs; nonpowered doors with automatic closing mechanisms require still more force to open and pass through. At the bottom of Mace's hierarchy is the manual revolving door, which requires strength, constant maneuvering, and accurate timing of when to enter and exit (R. L. Mace, personal communication, February 1998).

While presentation of these examples is helpful, it requires audience members to interpret and internalize the approach for themselves. It demands substantial commitment of listeners and requires the presenter to offer a very wide range of examples to assure that all aspects of the concept have been conveyed.

PRINCIPLE ONE: Equitable Use
The design is useful and marketable to people with diverse abilities.

PRINCIPLE TWO: Flexibility in Use
The design accommodates a wide range of individual preferences and abilities.

PRINCIPLE THREE: Simple and Intuitive Use
Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

PRINCIPLE FOUR: Perceptible Information
The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

PRINCIPLE FIVE: Tolerance for Error
The design minimizes hazards and the adverse consequences of accidental or unintended actions.

PRINCIPLE SIX: Low Physical Effort
The design can be used efficiently and comfortably and with a minimum of fatigue.

PRINCIPLE SEVEN: Size and Space for Approach and Use
Appropriate size and space is provided for approach, reach, manipulation, and use regardless of the user's body size, posture, or mobility.

FIG. 2. The Principles of Universal Design, Version 2.0, Copyright 1997: North Carolina State University, the Center for Universal Design.

THE PRINCIPLES OF UNIVERSAL DESIGN

Especially because of its initial emphasis and ongoing expertise in accessible housing which involves so many design specialties, the Center for Universal Design at North Carolina State University takes a broad view of design for people of all ages and abilities. Their belief is that universal design applies to all design disciplines, from landscape design, architecture, and interiors to product and graphic design and communications.

From 1994 to 1997, the Center conducted a research and demonstration project funded by the National Institute on Disability and Rehabilitation Research (NIDRR) titled "Studies to Further the Development of Universal Design." Staff of the Center for Universal Design conducted a series of evaluations of consumer products, architectural spaces, and building elements. The evaluations involved site visits, focus groups, observations, and personal interviews. The purpose of the evaluations was to determine optimal performance characteristics and use features that make products and environments usable by the greatest diversity of people.

Project staff then convened a working group of architects, product designers, engineers, and environmental design researchers from other research facilities to assemble a set of principles of universal design that would encapsulate the existing knowledge base. The Principles of Universal Design were established through collaborative efforts from individuals[1] at several sites, including the Center for Universal Design, Shepherd Spinal Center, J. L. Mueller, Inc., The University at Buffalo, Trace R&D Center, and Adaptive Environments Center. They reflect this group's vast collective experience in researching and practicing universal design in the diverse fields they represent. The principles were independently reviewed by a second group of practitioners[2] to critique, validate, and refine them.

The Principles of Universal Design (Center for Universal Design, 1997) (Fig. 2) apply to all design disciplines and all people and are useful for design, evaluation, and instruction. Each of the seven principles has four or five guidelines that elaborate on the concept embodied in it. They can be used to guide the design process, to evaluate existing or new designs, and to teach students and practitioners new to the concept what universal design encompasses and how it may be achieved. The principles are a work in progress and efforts are ongoing to make them easier to apply.

The Principles of Universal Design are presented in the following format: *name* of the principle, intended to be a concise and easily remembered statement of the key concept embodied in the principle; *definition* of the principle, a brief description of the principle's primary directive for design; and *guidelines,* a list of the key elements that should be present in a design that adheres to the princi-

[1] Primary authors of The Principles of Universal Design were (in alphabetical order) Bettye Rose Connell (The Center for Universal Design), Michael L. Jones (Shepherd Spinal Center), Ronald L. Mace (The Center for Universal Design), James L. Mueller (J. L. Mueller, Inc.), Abir Mullick (The University at Buffalo), Elaine Ostroff (Adaptive Environments Center), Jon A. Sanford (The Center for Universal Design), Edward Steinfeld (The University at Buffalo), Molly Follette Story (The Center for Universal Design), and Gregg C. Vanderheiden (Trace R&D Center).

[2] Reviewers of The Principles of Universal Design were Meredith Davis (North Carolina State University), Allan Eckhaus (Consumers Union), Susan Goltsman (Moore, Iacofano, & Goltsman), Paul Grayson (Environments for Living), Peter Orleans (Architect), Mary Jo Peterson (Interior Designer), Victor Regnier (Andrus Gerontology Center), John Salmen (Universal Designers & Consultants), Steven Sargent (Consumer Product Testing Labs), Polly Welch (University of Oregon), and Margaret Wylde (ProMatura Group).

ple. (Note: all guidelines may not be relevant to all designs.)

Principle One: Equitable Use

The design is useful and marketable to people with diverse abilities.

Guidelines:

(1a) Provide the same means of use for all users: identical whenever possible, equivalent when not.
(1b) Avoid segregating or stigmatizing any users.
(1c) Make provisions for privacy, security, and safety equally available to all users.
(1d) Make the design appealing to all users.

Example: building entrances. The main entrance to a building (and ideally, all entrances) should have a well-integrated and level or gently sloping approach, a door that automatically opens, and a flush or minimal (¼″) threshold. Every visitor to the facility should be able to use the same entrance(s).

Principle Two: Flexibility in Use

The design accommodates a wide range of individual preferences and abilities.

Guidelines:

(2a) Provide choice in methods of use.
(2b) Accommodate right- or left-handed access and use.
(2c) Facilitate the user's accuracy and precision.
(2d) Provide adaptability to the user's pace.

Example: automated teller machines (ATMs). Ideally, the ATM's screen is located where it can be seen and its control panel can be reached from a standing or seated position by tall and short users; the ATM card slot has a tapered opening to facilitate card insertion by those with limited manual control; the ATM's buttons are big enough and far enough apart to be pressed accurately by those with limited manual dexterity; its graphics can be read by those with limited vision or felt by those with no vision; and the device will provide feedback audibly for those who cannot see or read the screen. The process should be achievable by a slow novice user yet not frustrating to a quick experienced user.

Principle Three: Simple and Intuitive Use

Use of the design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.

Guidelines:

(3a) Eliminate unnecessary complexity.
(3b) Be consistent with user expectations and intuition.
(3c) Accommodate a wide range of literacy and language skills.
(3d) Arrange information consistent with its importance.
(3e) Provide effective prompting and feedback during and after task completion.

Example: imported furniture assembly instructions. An excellent example of simple and intuitive use is a furniture manufacturer who ships products all over the world. Rather than print the assembly instructions in several different languages, they eliminated text entirely. Instead, they offered a series of clear illustrations that match the furniture and showed small pieces magnified and exploded apart in the proper sequence for assembly (Fig. 3).

Principle Four: Perceptible Information

The design communicates necessary information effectively to the user, regardless of ambient conditions or the user's sensory abilities.

Guidelines:

(4a) Use different modes (pictorial, verbal, tactile) for redundant presentation of essential information.
(4b) Maximize legibility of essential information.
(4c) Differentiate elements in ways that can be described (i.e., make it easy to give instructions or directions).
(4d) Provide compatibility with a variety of techniques or devices used by people with sensory limitations.

Example: computer software. Ideally, information is provided in text for those who can read the words, pictorially for those who cannot, and audibly for those who cannot see. The computer should work with standard screen enlargement and screen reader software and with speakers or headphones. Technical assistance should be available via e-mail, the telephone, and the postal service.

Principle Five: Tolerance for Error

The design minimizes hazards and the adverse consequences of accidental or unintended actions.

Guidelines:

(5a) Arrange elements to minimize hazards and errors: most used elements, most accessible;

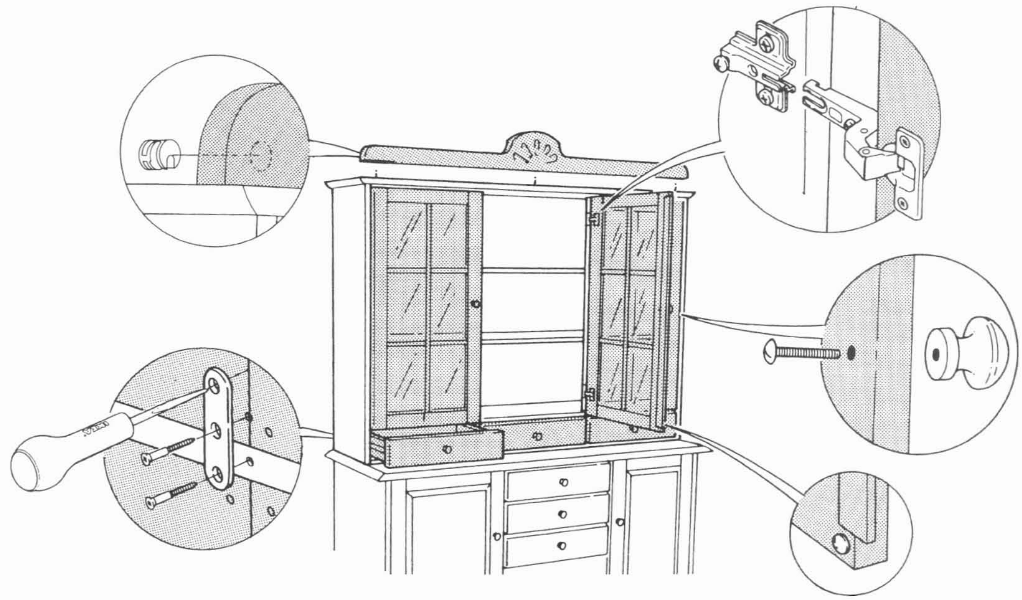

FIG. 3. Assembly instructions for imported furniture eliminate translation problems by providing clear illustrations without text.

hazardous elements eliminated, isolated, or shielded.
(5b) Provide warnings of hazards and errors.
(5c) Provide fail-safe features.
(5d) Discourage unconscious action in tasks that require vigilance.

Example: building features. Visitors to a public place should be able to navigate without risking physical danger. A color coding scheme can facilitate wayfinding, as can hallways that return to a common area rather than stop in dead ends; doorways to destinations can be painted in colors that contrast with the adjacent walls while doorways to private spaces are painted to match them; and doorknobs on doors that lead to mechanical rooms and other potentially dangerous spaces can be locked or abrasively textured.

Principle Six: Low Physical Effort

The design can be used efficiently and comfortably and with a minimum of fatigue.

Guidelines:

(6a) Allow user to maintain a neutral body position.
(6b) Use reasonable operating forces.
(6c) Minimize repetitive actions.
(6d) Minimize sustained physical effort.

Example: medicine bottles. When child protection is not a concern, bottles of medications should be easy to open. The bottle and the cap should be easy to grip and to turn and involve only a small range of motion (Fig. 4).

Principle Seven: Size and Space for Approach and Use

Appropriate size and space is provided for approach, reach, manipulation, and use regardless of the user's body size, posture, or mobility.

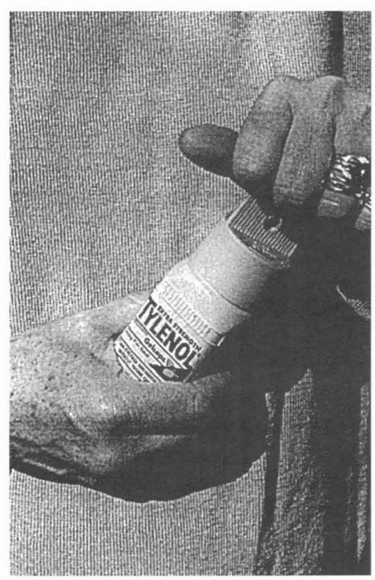

FIG. 4. Pain reliever cap has big tab and must be turned only ¼ turn to open. This facilitates grip and minimizes repeated twisting.

Guidelines:

(7a) Provide a clear line of sight to important elements for any seated or standing user.
(7b) Make reach to all components comfortable for any seated or standing user.
(7c) Accommodate variations in hand and grip size.
(7d) Provide adequate space for the use of assistive devices or personal assistance.

Example: toilet rooms. Wall-mounted components (e.g., toilet paper, trash can, belongings shelf) should be visible, easy to reach, and easy for all sizes of hands to use. The room itself should be large enough to fit a wheelchair and a personal assistant, child, or companion, if desired.

Note that the Principles of Universal Design only address the usability of designs. As indicated by Batavia and Hammer's (1990) criteria for evaluating assistive technologies, there are other issues of importance to consumers, such as affordability and durability of products. However, the Principles of Universal Design serve to specify those aspects of usability that are most affected by the range of human variation and that merit special attention from designers.

The Principles of Universal Design should apply to all phases of use. A product should be easy to try in a store environment, set up in the home, use the first time, use long term, maintain, repair, and dispose of.

APPLYING THE PRINCIPLES OF UNIVERSAL DESIGN

While the Principles of Universal Design are a landmark achievement in communicating the concept of universal design and all of its varied aspects, more work must be done to make them easier to apply. Two additional levels of information are planned that must be broken down by design discipline.

Below the levels of name, definition, and guideline come strategies and tests. Strategies specify ways that the guidelines may be achieved, and tests provide empirical tools to assess whether the guideline has been met. For example, for Principle Two: Flexibility in Use, some strategies for products to meet the guidelines would be

(2a) Provide choice in methods of use.

- Allow a choice of modes of input, such as keyboard or speech.
- Provide redundant modes of output, such as visual and auditory.
- Provide connectivity for assistive devices, if used, such as headphones or infrared devices.

(2b) Accommodate left- or right-handed access and use.

- Make the device symmetrical, reversible, or rearrangeable to suit both left- and right-handed users.

(2c) Facilitate the user's accuracy and precision.

- Make controls easy to grip and to move, whether they turn, slide, or press. Provide sufficient but not excessive friction in moving parts to facilitate precision.
- Make buttons large enough with sufficient space between buttons to facilitate accurate keying.
- If a key or card must be inserted into the device, slope or bevel the entry hole to facilitate its insertion.
- Provide a palm rest or elbow rest below control panels.

(2d) Provide adaptability to the user's pace.

- Allow novice users to move slowly and to access additional help messages, as needed. Allow expert users to move quickly and skip intermediate steps, when possible.

Some tests for this principle would be

- Can the device be used with a closed fist or open palm, either left or right? Can it be used with a bilateral closed-fist grip? Can it be used with a pointing tool? Can the device be used with an elbow, foot, or other body part? Can the device be used with imprecise movements/limited coordination, e.g., using the nondominant hand?
- Can the device be used from a seated or standing position? Can the device be used from different heights or different angles?
- Are built-in adjustments easy to make?
- Can the device be used with assistive technology, such as a hearing aid, a prosthesis, or a wheelchair?

ASSISTIVE TECHNOLOGY VS. UNIVERSAL DESIGN

The goal of universal design is to maximize the normalcy of disability, but assistive technology will always be needed. Because it will never be possible to design anything that can be used equally easily by everyone, individuals, especially those with the most severe disabilities, will always need some assistance from a device or another person.

Nonetheless, as often as possible, mainstream products should be made accessible. If mainstream products are designed with a universal design approach, the need for assistive technology may be reduced. At the same time, assistive devices should also be designed to be as universally usable as possible. If assistive technologies are designed with a universal design approach, they may serve a wider range of users and the need for additional devices may be reduced.

Universal design has other advantages, as well. These include

- reduced cost of a device due to greater economies of scale realized by mass production;
- greater availability of usable designs that were produced in quantity and marketed through a variety of common channels;
- longevity of a device that continues to serve people even as their abilities change;
- better reliability of devices that were mass produced;
- easier repairability of common devices;
- inclusion of a person with a disability in using the same tools as everyone else in the family for everyday activities; and
- lack of stigma associated with devices that are used by everyone.

Universal design may, in fact, reduce the amount of personal assistance and the number of special devices needed. When that cannot be done, it should make connection to standard assistive devices as easy as possible.

THE FUTURE OF UNIVERSAL DESIGN

The next frontier for universal design is industry. We understand universal design in the research and academic communities, but in order to make a difference in individuals' qualities of life, we must convince industry to change the way it operates and to accept and adopt the concept of universal design. What will attract industry? Unless universal design will give companies a competitive advantage, they cannot justify its practice.

The first thing companies need is statistical justification for practicing universal design. They need demographic information about the prevalence of disability and the aging of the world's population and details about the legal requirements for accommodating people with disabilities.

The second thing industry needs is a set of universal design performance measures against which to judge their designs for use by a diverse consumer base. These would assist them to maximize the usability of the products and environments they produce.

Third, industry needs guidance to market their products appropriately. Appropriate marketing is critical to the commercial success of universal design, a fact well understood by the originators of the concept and the term in the early 1970s. Advertising a product as being useful (only) for old people or those with disabilities can be the kiss of death for a company. Companies need to learn marketing techniques that will appeal to a broad audience without stigmatizing the product, the company, or the customer.

The primary benefit to industry of practicing universal design is that it will be more effective at serving a consumer base that is more diverse than most realize. This will result in greater consumer satisfaction and a more loyal customer base and has the potential to increase the size of markets. The early practitioners of universal design, such as Honeywell (home controls such as thermostats), Cuisinart (small appliances such as food processors), Whirlpool (large appliances and telephone customer assistance), and more recently Oxo (Good Grips® kitchen utensils) and Fiskars (Softouch® scissors and shears), have gained a considerable amount of free publicity about their efforts and a great deal of business from this exposure and the quality of the designs themselves. Their successes must be publicized more widely to entice additional companies to follow suit.

Two current trends increasing momentum toward wider universal design adoption are the globalization of the marketplace and the aging of the world's population. As the globe shrinks and competition for markets intensifies, design that accommodates diversity in language skills and life experiences will succeed. Also, as the world's post-World War II baby boom generation ages, design that reflects a belief that users are more important than art will thrive. These issues will only become more important in the coming decades.

In the meantime, rehabilitation professionals can serve their clients most effectively by first researching what solutions already exist. Often, the assistive device needed by a client is available through a mainstream catalog or even at a local store. Second, service providers should recommend products that are as universally usable as possible for the reasons mentioned above: easier availability, lower cost, better reliability, easier repairability, less stigma, and greater utility for all members of the family. Third, rehabilitation engineers should custom design devices only when necessary and even then should design not only for the current needs of the client but for his or her future needs and the needs of other family members as well.

Universal design reflects a belief that the range of human abilities is normal and results in inclusion of people with disabilities in everyday activities. The most significant benefit to the proliferation of universal design practice is that all consumers will have more products to choose from that are more usable, more readily available, and more affordable.

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