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Design Science
and
Design Education

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Abstract

Design sciences are technical or social sciences that focus on how to do things to accomplish goals. Design sciences emerge when skills-based professions move from traditional rules of thumb or trial-and-error methods to the use of theory and scientific method. Many forms of design are at this point now, including graphic design, industrial design, information design and design management. This is visible in an emerging transition from an arts-and-craft approach to a theory-based design. In this time of transition, the theoretical and intellectual content of design education takes on particularly great importance. This article will discuss some of the issues involved in the transition and in the kinds of design education that we require to successfully bridge two eras in the design profession.

Key Words

Design education; design science; design research;
Industrial design; information design;
Graphic design; design management.

Design Science and Design Education

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The Development of Design: from Evolution to Education

With a new century looming in front of us, it is tempting to title an article "Design Education for the Twenty-First Century." It would be easier still to give way to the millenarian impulse to write about "Educating Designers for the Next Thousand Years." In considering the kind of design education that we need today, however, it is more accurate to write about educating designers for a profession in transition. Medical education began the transition in the last century. So, too, did law. Engineering began around the same time, as did architecture. Professional education for business and management studies began a little over a century ago, but the big growth in management education has only taken place during the last fifty years. Information science is more recent still, and hasn't yet settled on a paradigm. It is no wonder that a profession rooted in centuries of craft tradition should be struggling to develop an education suited for today's world.

The beauty and the challenge of design education lies in those ancient arts that gave birth to design. Some areas of design go back millions of years. Industrial design began over two and a half million years ago *when homo habilis* manufactured the first tools. In a sense, human beings were designing even before we began to walk upright. Four hundred thousand years ago, we moved into the manufacture of [end page 54] [start page 55] spears. By forty thousand years ago, we had moved up to specialized tools. It wasn't that many thousand years before were playing flutes, making art and manufacturing needles to sew the garments of the earliest fashion designers.

Urban design and architecture came along ten thousand years ago in Mesopotamia. Interior architecture and furniture design probably emerged with them. It was almost five thousand years more before graphic design and typography got their start in Sumeria with the development of cuneiform. Since then, it's been one innovation after another.

For most of these millennia, innovations in design were handed down through a craft tradition. Guilds of artisans and craftsmen preserved the secrets and mysteries of their profession. The development of stonemasons was typical. The advancement of a stonemason through the ranks of the mason's guild involved three levels of expertise. These were "a personal development that grew from mastery of technique to mastery of construction to mastery of style: from skills to knowledge to creation" (Mollerup 1997: 34). According to Mollerup (1995: 46) "The three disciplines corresponded to three degrees of the stonemason's career. The *Geselle* had skills. The *Palirer* had skills and knowledge. And, finally, the *Meister* mastered skills and knowledge as well as creation."

Professions develop as history and circumstance shape them, and the borders between art, craft and science were often somewhat fuzzy. In early European medical schools, for example, the bloody, hands-on aspects of medicine were practiced by barber-surgeons. They did the dissecting in the earliest medical schools, standing in the surgical theater, while the professor of medicine -- a doctor of medicine -- sat on a raised platform reading from a book held up by one of his lecturers. Theory and practice were rigidly separate in all senses, academic, intellectual, and in terms of social status.

Things were different in the workshop of the master artist. The workshops of the masters saw a rich combination of theory and skill, science and art, craft and commerce. A great master might well be an architect who planned palaces and fortifications for his patron while conducting metallurgical, ballistic and chemical research for the cannon, shot and powder that would be used against his patron's enemies. In the Renaissance, the master architect of a cathedral, the painter who designed the altar-piece and the furniture designer who planned the altar itself might be the same person. The smith who shaped the chalice might work under the master's tutelage as might the stonecutters and woodcarvers who raised the building and made the furnishings that went inside. The studios and the workshops were one, and they were factories and schools as well.

The birth of academies and the development of the atelier tradition separated the fine arts from the practical and applied arts. This separation took different forms in different times and different places. Fairly uniformly, however, there came a distinction between fine art, high in status, and applied art or craft, lower in status and far less prestigious. At the same time, architecture retained a high status and devolved to high status schools and academies. At the highest levels, engineering often did when it wasn't incorporated directly into universities, though some engineering schools became slightly lower-status technical and polytechnic colleges. The crafts, on the other hand, were deemed both utilitarian and decorative. While many consider paintings decorative, the use of academic painting for propaganda, ritual and statecraft gave it a value and an esteem far higher that that accorded the decorative arts of glass or ceramics, metal-work or weaving.

This tradition lives on in the names that many schools still retain. Consider Norway's *Statens Kunst- og håndverksskole*. The school translates its name as *The National College of Art and Design*, but the literal translation means *The National School of Art and Craft*. Einar Haugen (1986: 191) translates the word *håndverk* as *handicraft*. Willy Kirkeby (1981: 173) translates the term as *trade* or *craft*. The social status of the term *håndverk* is revealed by the related terms, *handverk*; *handverker;* and *handverksmann*: Haugen translates them as (1986: 170) *handicraft*, *craft*, *trade*; *artisan*, *craftsman*; *artisan*, *craftsman*, *laborer*, worker. He translates (Haugen 1986: 191) the term *håndverksmessig* as *craftsmanlike* and *professional* but it also has the meaning *mechanical* and *uninspired*. [The school is now renamed Kunsthøyskolen i Oslo, a name that literally means "the art college in Oslo. The name is translated as Oslo National Academy of the Arts. – KF, 2005]

Until recently, all of Norway's design programs were taught in this school One reason that some designers favored the recent transfer of industrial design education from the *Kunst- og håndverksskole* to *Arkitekthøyskolen i Oslo* -- the *Oslo School of Architecture* -- was a significant rise in status. Industrial design education is no longer comparable to a craftsmen's education, but [end page 55] [start page 56] to the education of an architect. In the minds of many, this is comparable to the difference between pottery or glass-blowing on one hand and law or engineering on the other.

Design education has been linked historically to craft education. At the best, and there has been much good, this education has retained and promoted a sense of the plastic and tactile elements in design. For decades, however, the fight has raged among craft workers and artisans to be granted the same status as that given to the fine artists, and this fight for acknowledgment has resulted in an extraordinary amount of fine art in craft media. If this has in many ways been an advantage for art, it has often been a problem for design.

The search for artistic effect as a primary value in design has given us far too many design disasters: teapots that don't pour; tea kettles that burn the hand when they do pour; cups that deny the physics of liquids; chairs that tip over; furniture that induces physical stress; knives that can't be held safely when cutting; lemon squeezers that send as much liquid down the decorative legs of the utensil as into the juice cup; business brochures that can't be read if they are photocopied or sent by telefax; trademarks that can't be printed unless in an expensive full-color format; and so on. Every design professor can add examples to this list.

The challenge is not to recognize obvious disasters of design after they're made. That is easy. The challenge is to shape an effective process of design that yields effective outcomes. This must be an inquiry-based process, a problem-solving process linked to effective methods for design development.

This, in turn, requires the use of systemic thinking, a scientific approach. This took place in practice when science, art and craft were linked in the best workshops, at least to the level of the disciplines as they stood at the time. As it stands now, they are separated and disjoint. The general tendency among students in art schools and in the craft schools that aspire to their status is not to read, but rather to look at pictures. When little reading takes place often focuses on the current interests of trendy critics and connoisseurs. There are exceptions, but they are as notable as they are few. In general, art and craft based design schools have not been centers of reading or theory-building.

This is understandable. Schools and their culture are shaped by faculty, and design faculty generally come from an art or craft tradition. Reading and research have not been prized in the art and craft tradition. The tradition of research, writing and professional dialogue on which scientific progress depends has been, for the most part, absent.

The past holds many of our colleagues prisoner. These are intelligent people, often witty and articulate, dedicated to their craft. Even so, many, including those who teach in universities, are prejudiced against the university tradition of education based on science and theory. Those who oppose the scientific tradition of design theory dismiss it as mere "book learning." Some state openly that "real designers" do not use words. Rather, they say that that "real designers use their hands" to make things artifacts that will speak for themselves and for their makers.

Outstanding design artifacts do speak for themselves and for their makers. Nevertheless, artifacts do not articulate or clarify the design process. This is where the problem lies. The key difference between design and craft is not in the crafting or the beauty or the aesthetic quality of the artifact. These may be the same. It is a question of process. The design process begins above all with inquiry. Jens Bernsen (1986: 10) describes design as "translating a purpose into a physical form or tool."

Designed artifacts and natural artifacts have much in common, but designed artifacts are, finally, the result of a process of conscious evolution. Bernsen describes solutions in nature and design that "vary in purpose and are adapted to different environments." He writes that we use many of the same kinds of terms of describe the results of design and evolution, including purpose, economy of manufacturing and construction, beauty, interaction with the user, relationship to the environment.

"The fact that the designs of nature and the designs of man can be analyzed according to a common set of criteria," writes Bernsen (1986: 10) "stems from the fact that they have a basic property in common: they are solutions to a problem."

The title of Bernsen's book suggests a frame for the design inquiry: *The problem comes first*. The artistic approach is all too often a solution looking for a problem; a look or a style or an answer waiting to be settled on an unsuspecting client. This may be beautiful and the results may be artistic. The results may even evolve to fulfill a need. But unless the process is a conscious problem-solving process, it is not design. [end page 56] [start page 57]

Five Warnings

At this point, five warnings will clarify my view.

First, the scientific approach to design does not contradict the artistic aspect of design. Successful design artifacts have aesthetic values and qualities, sensual and engaged. All designed objects, tactile, mechanical, visual, auditory, are mediated through the physical senses. Sensory quality is a central issue for articulate objects that work in a physical world. Since the purpose of this article is to consider the design process and education designers that need to carry out the process successfully, I will not here focus on the issue of sensation or aesthetics. Even so, the aesthetic dimensions remain important.

A good design process must embrace the aesthetic as well as the scientific. The central difference is that one does not start with the look and feel, but rather with the parameters of the problem. Look and feel and tone and feeling and flavor emerge in the solution phase once the parameters of the problem establish the basic requirements of a solution. The most successful design artifacts join science, art and commerce as effectively as the life of a good medieval workshop.

Second, a good artifact may evolve without a conscious problem-solving process. We cannot know what goes on in the mind of designer. We can not, therefore, know whether an artifact emerges through the process of scientific discovery or through the process of evolution and selection, justified afterward by clever language. In addition, there arise the questions of intuition and multiple languages. Intuition plays a role in every science and intuition often involves non-verbal and -- at first -- inarticulate thinking. The many ways in which people represent ideas and express their work also mean that there are many possible languages of articulate inquiry.

Entirely distinct from the issue of many forms of articulation and role of intuition, it is possible for a designer to stumble upon the design of an artifact or muddle through to a solution without conscious effort. Without conscious problem solving, however, including the proper use of intuition, we are not talking about design but evolution. The work of the unconscious designer is no more and no less a product of evolution than the tools evolved by *homo habilis* in 2,500,000 B. C. The evolved artifact may have a fancy package and a trademarked name, a snappy look and a good effect, but unless it is the result of a proper design process, the individual who produced it has not yet learned to walk upright as a designer.

Third, I assert the need to develop a design science for the design professions. I do not argue that the design profession or design education have yet become scientific. Quite the contrary. Evidence suggests that most design practice remains a craft. Even so, an emerging design science of design is becoming visible. A number of leading designers use scientific method and an articulated problem-solving process. A growing number of designers, scholars and scholar-practitioners are active in the field of design research. A few outstanding design schools teach theory, research and problem solving, and these schools require a heavy diet of reading and writing along with the exercises and projects that most design schools require. I do not argue that scientific method has transformed the practice of design. I argue that it should.

Fourth, science and the scientific method should not be identified with positivism. I will not discuss the many approaches to science because this article is not the place. There are many valid approaches to science that can be usefully applied to design and design research (Alvesson and Sköldberg 1994; Argyris, Putnam and Smith 1985; Feyerabend 1962, 1974, 1977, 1978, 1987; Galtung 1967; Gleick 1987; Johannessen, Olaisen and Friedman 1997; Lincoln and Guba 1985; Newton-Smith 1981; Olaisen 1991; Robson 1993; Rock 1979; Scheffler 1982; Stegmeuller 1979; Suppe 1969, 1977, 1978; Waldrop 1992). The appropriate selection of method depends on the problem at hand. My own approach is far from positivistic, but positivistic science also offers valid methods for certain fields of design research.

Science and scientific method involve a rich relationship between theory and practice, between conceptualization of the world and the world itself, between tacit understanding and the ability to articulate tacit understanding as conscious knowledge. This conscious knowledge is science, the understanding of how things are and how they work based on fundamental principles.

Fifth, and most important, it is my belief that the comprehensive design process is a rich, complex integration of the scientific and the sensual, the intellectual and the intuitive. It is impossible in a short article to articulate the full range of processes that comprise effective design. The effective designer has as much in common with Isaac Newton as with Picasso, [end page 57] [start page 58] and more in common with either than with Philippe Starck. The outstanding designer has as much in common with Hokusai as Marie Curie, and more in common with both than with the latest design comet flashing briefly across the face of the sun while a gaggle of fans mistake the momentary shining tail for the brilliance of a star.

It is my assertion that the science of design should be a warm, rich science that combines industry and art. It should lead to an industry that yields jobs while sustaining the environment. It must lead to an art that solves problems and meets goals while enlivening the senses. If we are to educate designers rather than hand out diplomas to new generations of the post-modern *homo habilis*, this must be our purpose.

The Concept of Design Science

Design sciences are technical or social sciences concerned with how to do things to accomplish goals. Design sciences emerge when skills-based professions move from rules of thumb based on trial and error to instructions based on scientific method. The design professions are at this point now.

Nobel laureate Herbert Simon defines the goal of science in general as understanding "things: how they are and how they work" (Simon 1982: 129). Next, he defines design. To design is to "[devise] courses of action aimed at changing existing situations into preferred ones" (Simon 1982: 129). This clearly applies to the professions we identify by using the word "design," including graphic design, information design and industrial design. In this context, design management is also a form of design.

The different forms of professional design practice require a process incorporating the strategic and managerial aspects of design as well as the hands-on developmental application of design. These move from thinking, research and planning at one end of the process to physical manufacture, assembly, packaging and presentation at the other.

Design is a complex practice that requires many different skills. These skills are required regardless the professional background or title of the designer who takes responsibility for a project. The world often requires an individual with the title "industrial designer" to execute projects that might elsewhere be carried out by a design manager or an information designer or a graphic designer. The same holds true of these other professionals. At the cutting edge of where practice meets the working world, no aspect of design education or design practice is truly separate from any other. The only designers who specialize completely are junior practitioners who execute specific tasks on the direction of senior designers.

When Design Education Fails

Design education can be divided into two camps. These camps emerge from differing attitudes towards design. One philosophy treats design as the skill of making an object or an artifact. If design is making an object or an artifact, we can -- according to this philosophy -- successfully educate design students by teaching them to reproduce selected objects or artifacts. This is the model of education that has until now been most common in design schools. This is craft education or vocational education. The vocational model is sometimes dignified with the title of professional education, but an emphasis on reproducing and producing objects remains vocational in scope. The majority of design educators today take the vocational perspective.

The other philosophy treats design as a knowledge-intensive process that involves selecting goals, then developing and executing strategies to meet those goals. Good execution is necessary, but the first step is a knowledge process. If design is a knowledge-intensive process, designers are knowledge professionals subject to the uncertainty and transformations affecting all professions in the knowledge economy. We can determine some of the skills that designers need, but design education can no longer be based on exercises intended to teach students how to reproduce or improve selected objects. Instead, we must equip designers with the intellectual tools of the knowledge economy: analytical, logical and rhetorical tools; problem solving tools; the tools of science.

Consider the challenge designers face when working with firms. Few companies are large enough to support a design staff. Even those firms that can support one designer are rare enough. Design is generally an external function and designers must rely on a briefing to do their work. The briefing system has advantages: it provides a needs assessment, a problem statement and a description of desired outcome, the preferred situation that the designer must provide. But the saving in time and effort that a briefing represents means [end page 58] [start page 59] shaping an inherently specific and limited problem statement. By the time the briefing is completed, many possibilities have been considered and rejected in favor of the single outcome stated in the briefing. A designer can never be better than the briefing.

The success of a design project depends on two issues that external designers find difficult to control. One problem is the improperly developed briefing. The most frequent problem of the improper briefing is a mismatch between the description of a desired outcome and unstated expectations that may differ from or conflict with the briefing. Preparing a good design briefing demands knowledge of design problems and their outcomes. Lacking that knowledge, an organization may brief a design firm by asking for a specific product or process without recognizing that the stated specifications will not lead to the desired results. The problem is compounded by designers who accept a briefing without recognizing it as the flawed product of an improperly managed design process.

This situation is made worse by the generally poor knowledge of designers concerning the broad circumstances of life and work outside the narrow frame of design. This is rooted in the lack of an education for the theoretical complexity of the design task. The result is that many design projects fail to achieve appropriate goals.

Poor solutions are common. Good solutions to the wrong problem are just as common and just as bad. When design fails to achieve preferred situations, business leaders view design as a less useful investment than other choices that compete for funding.

Designers must have a broad enough background to understand the wide range of issues that will affect their work. “In design, as in any problem-solving process, it pays to analyze the problem before creating the solution. It is better to use 10% of the resources to find out how to use the remaining 90% properly than to use 100% of the resources the wrong way” (Mollerup 1993: 23). Problem solving and analysis must be the foundation course of any design education.

Developing a Theory-Rich Discipline

The immature state of the profession is one cause of failure in design practice. Successful design requires explanatory principles, models and paradigms. The design profession has developed few of these. Achieving desired change requires a foundation in theory. This demands a conception of preferred situations in comparison with other possible situations and an understanding of the actions that lead from a current situation to a preferred one. General principles are required to predict and measure the outcome of decisions. This is what W. Edwards Deming (1993: 94-118) terms profound knowledge, comprised of “four parts, all related to each other: appreciation for a system; knowledge about variation; theory of knowledge; psychology” (Deming 1993: 96).

The fact that design is young poses challenges to the development of a rich theoretical framework. In order to develop this framework, a community of researchers must identify themselves and enter into dialogue. This process has only recently begun. In the development of a professional research community, “...discussion about the scope and content of a young field of research helps to form the identity of its scientific community. Internal organization and boundary definitions are central means for the social institutionalization of a specialty. The exchange of opinions and even disputes concerning the nature and limits of a field help to construct identity and thus become bases for social cohesion” (Vakkari 1996: 169).

In this context, “conceptions of the structure and scope of a discipline are social constructs that include certain objects within that domain and exclude others. Depending on the level of articulation, the outline of a discipline dictates what the central objects of inquiry are, how they should be conceptualized, what the most important problems are and how they should be studied. It also suggests what kind of solutions are fruitful. Although articulation is usually general, it shapes the solutions to specific research projects. This general frame is the toolbox from which researchers pick solutions without necessarily knowing they are doing so” (Vakkari 1996: 169).

The concept of profound knowledge establishes prerequisites for a design science toolbox that permits broad understanding linked to predictable results. One central challenge for design is educating designers.

Most design education now takes place in universities or design schools that have are now defined as colleges or university level schools. Some kinds of design education function within well defined domains such as industrial design, graphic design, textile design or furniture design. Other forms of education involve several design disciplines or even sev- [end page 59] [start page 60] eral professions. These include information design, process design, product design, interface design, transportation design, urban design, design leadership and design management.

No single factor determines the location of a design program in a specific department. All intelligent programs include courses that permit designers to move beyond craft skill and vocational knowledge to professional knowledge. These programs integrate specific knowledge with a larger understanding of the human beings for whom design is made, the social circumstances in which the act of design takes place and the human context in which designed artifacts are used. They also develop general knowledge of industry and business. A broad platform enables designers to focus on problems in a rich, scientific way to achieve desired change.

Education for Design Science

University education is rooted in the sciences. Even the arts and humanities attempt to understand “how” and “why” in contrast to the simple exercise of personal taste. As a result, university-based professional schools in disciplines such as business, law or engineering struggle with the challenge of educating for a core profession in a broad intellectual framework. Herbert Simon contrasts the older professional schools against the newer, defining the dilemma that schools face as they grow from professional education to education for the professional practice of a design science.

“The older kind of professional school,” Simon writes (1982: 131), “did not know how to educate for professional design at an intellectual level appropriate to a university; the newer kind of school has nearly abdicated responsibility for training in the core professional skill.”

Design schools -- with the possible exception of information science schools -- are the newest professional schools of all. They were previously vocational schools, trade schools or craft schools. Some were part of art or architecture academies emphasizing the craft approach. Design faculties often struggle with the challenge of new responsibilities and new curriculum requirements. This is particularly apparent when design schools try to build doctoral programs. Most design faculty are new to the university milieu. The majority of design teachers come from vocational backgrounds in the visual arts and crafts. A significant minority come from the liberal arts and humanities. A much smaller minority come from engineering and the applied sciences, from the physical or social sciences.

The challenge design schools face is the transition from an education in *crafting things* to an education in *understanding things*. One must do things to achieve results, but the classic distinction faced by practitioners of a design science is the distinction between "doing things right" and "doing the right thing." Doing the right thing requires a decision on what to do. That requires a design decision prior to technical facilitation.

To prepare designers intellectually for today's needs, design education requires broad, scientific values and profound knowledge. To prepare designers to produce artifacts, design education requires experience rooted in the physical craft of design. These two forms of education are in some ways at odds. In equally important ways, they can combine to great effect.

The problem is not goals but faculty competence and teaching methods. The faculty required for the earlier vocational education came from a different background and a different world view than faculty needed for theory-based education. These two kinds of faculty tend to be at odds with one another, teaching toward different goals and using different paradigms. Nevertheless, a solid foundation in material culture and physical technique can be combined with a thorough scientific education. There are schools that achieve these twin goals. The difference, when there is one, is not a difference between knowledge of physical issues and artistic maturity. The difference is a difference between over-specific vocational training and broad professional training.

The distinction between training for the sciences and professional training has begun to vanish in many fields, but the need to produce practical outcomes tends to keep professional schools oriented toward the real world. This often means a struggle between and among faculty members. The fight is not always easy. Simon points out (1982: 131) that it was not long ago that engineering schools "needed to be purged of vocationalism; and a genuine science of design did not exist even in a rudimentary form as an alternative. Hence the road forward was the road toward introducing more fundamental science."

Simon quotes Karl Taylor Compton, whose 1930 inaugural address as president of MIT stressed the fundamental sciences. Compton [end page 60] [start page 61] (1930) called for a close examination of all courses "to see where training in details has been unduly emphasized at the expense of the more powerful training in all-embracing fundamental principles."

Emphasizing details at the expense of a comprehensive view is not only the distinction between scientific and vocational education. It is a core problem in the design process. In Buckminster Fuller's book on *Comprehensive Design Thinking*, John McHale wrote that "... one of our major problems in thinking today is the use of language systems which still represent a fixed structurally compartmentalized world view. The terms available to us for the expression of dynamic, rather than static, concepts are far from satisfactory" (McHale 1965: unpaged).

A dynamic world requires dynamic concepts. Artifacts that function in this dynamic world must rest on an effective understanding of the world itself. Traditional artifacts worked well enough in a more static world. Simple artifacts as chairs, spoons, or tents work well because they fill fairly static roles. Even so, it is possible to compare static and dynamic concepts by comparing the performance of traditional artifacts with the same artifacts designed and reengineered using a scientific approach. The difference in such a simple artifact as a spoon can be astonishing when the traditional spoon is compared, for example, with an ergonomically designed spoon.

"Dining is a simple, everyday matter for most of us. ... The mechanics of eating -- the hundreds of minor steps that take place during an everyday meal -- receive even less thought than the act of eating. Few people count the number of specific, single acts required for the consumption of a meal. Some people must. For those with impaired strength and mobility, every motion can be a difficult, painful experience that robs the most basic human act of its joy. ... Think of a simple business lunch [using a spoon to perform the] grasp-scoop-and-lift motions of the wrist and arm to consume a small bowl of soup, ... Several hundred times a day, we perform basic mechanical work in order to eat. When the ability to handle the biomechanics of dining is impaired, the quality of life is dramatically diminished" (Friedman 1991: 737).

To make a spoon that works for everyone requires a scientific approach. To make such a spoon, Maria Benktzon and Sven-Eric Juhlin of Sweden's Ergonomi Design Gruppen conducted a rigorous study of the act of eating. They began with research, but their goal was neither theory nor a publication. It was the development of working tools. Their method has become a classic example of design as a design science: research, a project team approach, user involvement in the development and testing of prototypes, thorough testing of selected models and, finally, mass production (Benktzon and Juhlin 1984; Benktzon and Juhlin 1989; Boman 1983; Boman 1988; Hiesinger and Marcus 1983; Lindkvist 1983; Lindkvist 1988).

The robust scientific approach makes these products an important contribution to design for the disabled and an important contribution to the rest of society through its exemplary design methodology. The marriage of scientific method and practical outcome is the goal to which so many design thinkers address themselves (Compton 1930; Friedman 1991; Fuller 1964; Fuller 1965; Fuller 1967; McHale 1965; Simon 1982).

Effective design requires appropriate methods and rooted understanding. Design in the industrial world is handicapped by outdated methods. The symptoms are rigid design thinking, the confusion of artistic solutions with design solutions, or -- just as bad -- the failure to understand the need for the union of grace and function in optimal design (Friedman 1991: 737). While traditional training can lead to tacit knowledge, it represents the virtues as well as the vices of habit. To be useful, habitual knowledge must possesses critical comprehension along with behavioral roots.

Johan Olaisen (1996a: 10-11) writes that "Critical comprehension also depends on a generalized store of knowledge generated through habitualization. The processes of comprehension and habitualization are central aspects of learning understood as knowledge formation. ... many authors associate habitualization with stagnation and the absence of learning. To the contrary, it should be evident that comprehending things anew at each encounter is impossible. For that reason, the process of making things obvious is as important to human conduct as critical comprehension."

Traditional Training, Teaching Practice and Cognitive Fields

If we contrast traditional artifacts with contemporary manufactured artifacts, we find that traditional artifacts often embody a deep and thoughtful practice of conceptualization. Rules of thumb join together with theory and philosophy to produce a broader meaning than [end page 61] [start page 62] the simple surface of the object would indicate, a practice not entirely revealed by the physical act of production. Blomberg (1994: 48-71) describes the powerful juncture of world-view, religion, philosophy and craft that comprise the art of making, judging and handling the Japanese sword. These blades were a product of sophisticated metallurgical art and a science of observation and transmitting the art. This was the outcome of a rich world view that can be seen as a method of theorizing in practices of manufacture and action.

Lowry's (1985) descriptions of the Yagyu school of swordsmanship linked using the sword with philosophy and world view. This was transmitted through exercises that generate tacit knowledge and through a specific doctrine that generates articulated knowledge. Rich theories lie behind the writings of the sword masters (Musashi 1974; Musashi 1982; Musashi 1993, Yagyu 1993), writings that weave theory and practice together.

Rich -- or "thick" -- traditions stand in sharp contrast to the vocational approach to design training. This traditional development of situated knowledge is developed through years of practice-into-theory-into-practice supported by immersion in classics, the arts, a foundation in philosophy and an ethical world view. All of these stand in contrast to the short, career-oriented, pragmatic approach to design that forms much design education today. This engagement in a rich, philosophical tradition is closer to Buckminster Fuller's world view than to the world view expressed in the curriculum at many design schools today (Fuller 1981; Fuller and Dil 1993). These world views give rise to a cognitive field, and it is from the development of cognitive fields that sciences arise.

Pertti Vakkari (1996: 171-172) describes a cognitive field "as a sector of human activity aimed at the acquisition, diffusion or utilization of knowledge of some kind, whether this knowledge is true or false. The family of cognitive fields can be partitioned into two discrete subsets: the subset of research fields and that of belief fields. Belief fields include religions, political ideologies and pseudosciences. Research fields include the humanities, the basic and applied sciences and technology, including medicine and law. What characterizes a research field is active research or inquiry of some sort, that is, the formulation and solution of problems, the invention of new hypotheses or techniques." In the comments, that follow, it is useful to compare this description with Simon's (1982) descriptions of science, design and design science.

Vakkari (1996: 171-172) cites Bunge (1982) on the eight criteria that define any specific science. "1) The general outlook of philosophical background consists of an ontology, epistemology and the ethos of the free search for truth. 2) The formal background is a collection of up-to-date logical and mathematical theories. 3) The domain or universe of discourse is composed exclusively of real entities. 4) The specific background is a collection of up-to-date and reasonably well-confirmed data, hypotheses and theories developed in other fields of inquiry relevant to that particular field. 5) The problematics consists exclusively of cognitive problems concerning the nature of the domain as well as problems concerning other components of the particular field. 6) The fund of knowledge is a collection of up-to-date and testable theories, hypotheses and data compatible with those in the specific background developed in the particular field at previous times. 7) The objectives or goals include discovering or using laws of the domain, systematizing into theories hypotheses about the domain and refining methods. 8) The methods consist exclusively of justifiable procedures open to scrutiny."

"Any cognitive field that satisfies these conditions," writes Vakkari (1996: 172) "will be said to be a science. Although this definition mainly fits the natural sciences, it can also be applied to analyzing other types of science."

Vocational education was first used to teach large groups of workers the rudiments of their craft for the first factories of the industrial age. While vocational education has progressed beyond the transformation of farm boys and country girls into factory hands and mill workers, developing situated knowledge is generally left to the process of work itself. Those with the good fortune to have had the right combination of skill, intelligence, on-the-job development, mentoring and happy circumstance develop situated knowledge. Most don't benefit from the right mix of circumstances, including those who might have attained expertise or mastery given the right opportunities. That's one reason there are so few experts.

Situated knowledge requires reflection along with habituation. Developing reflection was one purpose of introducing secondary subjects and theoretical practice to the traditional Japanese arts. This distinguished the devel- [end page 62] [start page 63] opment of situated knowledge from vocational habit. Reflective practice is a form of critical study.

Reflective practice shapes the powerful distinction between vocational training and thick traditional teaching. Subjects beyond the immediate vocation played an important role in the development of reflective practice and finally mastery. Lowry’s description (1985: 134) of the role played by the game of *go* in the education of a samurai offers one example. He describes a game so simple that “in a single afternoon, a person can be taught all the rules and concepts of go and in Japan, schoolchildren play it regularly. Despite the outer simplicity of the game, however, it strategy is of such an advanced nature that ... the samurai pursued it as an excellent way to learn battlefield tactics.”

Expertise requires the reflection that gives articulate form to tacit knowledge through clear, understandable description. This takes time, and modern education for the design professions can’t afford the years and decades of training that were required for traditional arts in Japan or the pre-industrial development from apprentice to journeyman to master.

Time constraints are a predictable outcome of politically-determined education policy in the industrial world. The educational system in the industrially developed nations is built on the broad political platform of education for all. Democratic polity guarantees a basic minimum education for everyone and proposes access to advanced knowledge for many who demonstrate potential talent for expertise. The result is a broad, general education that distributes resources across the general population. The economics of this broad general education prohibit the intense personal instruction that leads from apprenticeship to mastery.

A Japanese master might take many apprentices and promote a reasonable number to journeyman status. Few could hope to be acknowledged as masters. Generally, only one in each generation of students might inherit the title of his teacher. While the European guilds promoted many to journeyman and a higher number to mastery than the Japanese, access was still limited. In Europe, too, education for craft mastery was based on the workshop tradition of highly personal attention. The economics of modern education can’t support this kind of individual attention.

We accept many students. We must produce many graduates. Our annual cohorts number from the dozens to the hundreds, depending on the school and its size. We send graduates out to find their own way, hopefully prepared to take responsibility for their own development. Even though we can coach, we cannot conduct an education that leads to situated knowledge in the old tradition. As a result, our graduates are often ill-prepared for the responsibilities that await them.

The lack of preparedness in graduates doesn't rest on a distinction between traditional education and modern education. It rests on our ability to shape an education that gives rise to situated knowledge. This is requires a distinction between vocational education and a scientific professional education that leads to understanding "things: how they are and how they work" for those "who devise courses of action aimed at changing existing situations into preferred ones" (Simon 1982: 129). It requires us "to educate for professional design at an intellectual level appropriate to a university" together with "training in the core professional skill" (Simon 1982: 131), a proper balance of "training in details" with a "powerful training in all-embracing fundamental principles" (Compton 1930). Fortunately, there is a way to achieve these goals.

Critical Foundations for Scientific Learning

To understand how things are and how they work in a scientific way Simon (1982: 129) requires a foundation in the act of critical inquiry. The scientific enterprise begins when scholars move beyond the act of transmitting what others have said to explore for themselves what is true and what isn't. This, in fact, is how science began. It remains a radical approach in a world governed by reference to established authorities and the sources esteemed by each profession as its classics.

Human beings seek agreement. Agreement is the basis of social cohesion and agreements shape the social context of every human activity. It is problematic to question the common understandings that shape the context of any science or profession. The accounts of every development in the history of ideas make that clear (Bennis 1989; Boorstin 1985; Fuller 1964; Fuller 1965; Fuller 1967; Fuller 1981; Fuller and Dil 1983; Gleick 1987; Kosko 1993; Kuhn 1970; Kuhn 1977; Lewin 1993; Waldrop 1992). If full fledged scholars face problems when they raise questions, one can [end page 63] [start page 64] imagine the anxiety that students face when they dare to question the profession into which they seek entry.

The growth of any discipline from imitation to exploration depends on critical inquiry. Critical inquiry gained its first strong foothold in the industrial democracies when the Royal Society was chartered in 1662 to pursue knowledge in purely scientific terms (Boorstin 1985: 386-417). Their motto was a celebration of inquiry: *Nullius in Verba*, "Take nobody's word for it. See for yourself." According to Boorstin (1985: 394) "The new currency of knowledge was the product of a special form of experience, to be known as experiment." The exchange of ideas among colleagues who appeal to empirical validation remains a central process in science today.

Experimentation makes it possible to measure truth or validity based on direct observation. It becomes possible thereby to attempt broad understandings of how things are and how they work. Hypotheses can be subjected to tests. One can discern greater and lesser validity among competing hypotheses. Experimentation makes it possible to shape theory. Theory, in turn, makes it possible to predict outcomes which can again be subjected to validation. Valid theories made richer predictions possible, and so it is that a structure of scientific knowledge begins to grow.

This is a crude picture of science, but I offer these ideas to demonstrate the need for critical inquiry if we are to approach design in a scientific way. Vocational education is based on the transmission of authoritative patterns, taught by drill and memory. This is no way to educate designers who are expected to shape effective outcomes based on a genuine understanding of things and how they work.

Research also play a role in the ability of faculty members to create effective design programs and to teach them. The requirement that senior faculty must do more than transmit what others have said, that they must be able properly to evaluate what is true and what isn't is the justification for the requirement that senior faculty in most disciplines conduct original research. This is a different kind of research than what is in many colleges termed the "research equivalent" deemed valid for art and craft departments: an exhibition of artifacts. Exhibiting the products of one's studio may be valid research for teaching art or craft, but it is not appropriate research for design. Design research involves the discovery of generalizable solutions to questions of problem and process. The inability of art-and-craft-trained faculty to conduct generalizable research is one more reason for the problems so many design schools face in creating doctoral programs. Senior design faculty who teach technical skills must be able to conduct broad research as well as teach specific skills. Those who cannot do so ought not to be entrusted with senior authority over curriculum planning or the power to accept or advance students beyond the scope of their specific technique courses.

The Uses of Skills Training

Training, exercise and drill have their purposes. Drill is a valid way of mastering and ingraining any practice that must become situated knowledge. One must practice, drill and exercise to drive a car, master a sport, learn a language, develop an unconscious sense for mathematical patterns, play a musical instrument -- or handle many of the technical craft tasks required of a designer.

Mastery is more than situated knowledge. Mastery requires the ability to look deeply into the ingrained patterns and analyze them. This is what distinguishes the master from the technician. Here, we speak of the great racing driver, the athletic champion, the person who has engaged the spirit of a language to move beyond daily use or fluency to eloquence, the insightful mathematician. In each of these fields, as in music or design, one sees a range of talent that ranges from no knowledge whatsoever to the deep unconscious competence that characterizes expertise. The journey from apprenticeship to mastery always passes through analysis and the ability to articulate the necessary knowledge.

Many professions require the kinds of situated learning best taught by a combination of analysis and memory: anatomy for physicians, business accounting and statistics for general managers, and many areas of design. We need vocational training because the sciences of design require physical skills and an accumulation of patterns that must be memorized and understood. The problem is not vocational training. The problem is vocation training based on projects and exercises to the exclusion of broad analytical and synthetic knowledge. The problem emerges when we mistake vocational training for professional education, something that often happens when institutions of vocational education take on professional status without changing nature, structure or faculty. A comparable prob- [end page 64] [start page 65] lem emerges when a professional faculty takes on university status without preparing for inquiry-based learning. This is what Compton (1930) meant in discussing "training in details ... unduly emphasized at the expense of the more powerful training in all-embracing fundamental principles."

The road to principle begins when students undertake their own inquiry. This is a difficult and challenging approach to education, but it is necessary if students are to find their way into scientific method. Warren Bennis (1989: 6) writes that "...the best information we have suggests that adults learn best when they take charge of their own learning." While faculty members can't abandon their responsibility to teaching, they must recognize the difference between showing their own knowledge and helping students to learn. A teacher who merely demonstrates his own knowledge through lectures is not teaching. He is merely the smartest student in class.

Anders Skoe's theory of learning (Skoe 1992) builds on inquiry and experiment. Skoe uses a teaching technique he terms *Progressive Action Learning*, in which students are encouraged to shape an understanding of cognitive reality by addressing tasks, making mistakes, analyzing the results, and attempting tasks again in a cycle that leads from incompetence to mastery. Skoe's method is built on the assumption that it is not the job of a student to be perfect or give right answers every time, but to learn. The goal of study is to move as far along the path from incompetence to mastery as is possible for any given individual.

Skoe builds on the well known *Behavioral Learning Model* that describes a path from unconscious incompetence through conscious incompetence and conscious competence to unconscious competence. Skoe's version of the model (1994: 54) traces several steps. In unconscious incompetence, the learner -- that is, the neophyte or apprentice -- doesn't know that he doesn't have the skills or knowledge he requires to address a task properly. Conscious incompetence is a valuable and important step. It entails the recognition of missing skills and the need to learn. Conscious competence moves through the long, and sometimes painful learning process, awkward at first, with increasing skill later, but requiring conscious effort at all stages. Skoe's special contribution is the articulate recognition of the emotional factors that accompany the different stages of progress. He notes the danger points where awkwardness and frustration lead to reversals, those moments when students turn back to the comfort and security of earlier stages.

At every stage along the path from unconscious incompetence to unconscious competence, the task of teaching is the task of helping learners to identify and articulate the issues and tasks they face, intellectual and academic, personal and professional. That progress moves them from immaturity to maturity, from dependent engagement to independent knowledge. The special role of the teacher in this work is shaping the context for growth. This is the core of the teaching task. Individual research and personal expertise form a necessary background for teaching, but the activity of teaching itself primarily involves guiding the student along the road to knowledge.

Critical Inquiry in Education

When design students leave school, they have two major approaches to knowledge. They can rely on what they have learned to the exclusion of everything else or they can build on what they have learned by taking responsibility for their own development. The first path has been historically acceptable, but today's knowledge economy requires analytical and critical skill for all but the most menial positions. No job that requires education can be done effectively on the basis of rote learning. Even simple jobs demand individual initiative and judgment. These skills that do not suddenly blossom the day after leaving school. Design education must therefore launch students on a path of inquiry and coach them from their first steps to independent ability.

While nearly every approach to knowledge requires overcoming obstacles, Bennis (1989: 7) notes that these kinds of "...impediments can be dissolved by close scrutiny and the right questions at the right time." Offering provocative questions at the right time is a way of coaching and guiding students from dependence on authority to the ability to inquire and to shape appropriate perceptions. This is the key step in a journey that demands the ability to put authority aside in an effort to explore issues from fresh perspectives. Learning based on memorizing facts and repeating them back to a teacher only gets in the way. As Bennis (1989: 7) puts it, "...What we need to know gets lost in what we are told we should know."

Since students must practice new-found skills to master them, practice continues to play a role in education. The key to learning is [end page 65] [start page 66] linking practice to the critical analysis that transforms experience into knowledge. Just as the act of articulation transforms the tacit knowledge of an expert into teachable knowledge, so the act of critical analysis helps to transform experience into the understanding on which knowledge is based.

The issue of knowledge revolves around the relationship between theory and practice. Theory must be tested in some form of experimental practice to be proven valid. Theory must be linked to working practice to be shown as useful. Practice, however, is not in itself the final criterion of theory-rich validity. One can clearly engage in a practice without understanding what one does, let alone why any given practice succeeds or fails. For that kind of understanding, one requires a theoretical framework. There is a distinction between doing and knowing. Design science requires both.

To reach from knowing to doing requires practice. To reach from doing to knowing, one requires the articulation and critical inquiry that allows a practitioner to gain reflective insight. "Experience alone, without theory, teaches management nothing about what to do to improve quality and competitive position, nor how to do it" writes W. Edwards Deming (1986: 19). "If experience alone would be a teacher, then one may well ask why are we in this predicament? Experience will answer a question, and a question comes from theory." It is not experience, but our interpretation and understanding of experience that leads to knowledge. Knowledge, therefore, emerges from critical inquiry and scientific knowledge arises from the theories that allow us to question and learn from the world around us.

Training students to reproduce tasks with some consistency has a purpose in some part of an education. Memorizing key facts and concepts serves a purpose on occasion, but -- as will be seen below -- those occasions are in reality quite few. Asking students to reproduce accurately the words they hear in lectures or read in books is almost always counterproductive. This kind of learning directly opposes and works against the kind of learning that enables students to transform experience into knowledge. This presupposes and requires critical inquiry. Critical inquiry immerses the student in a process that requires building rich cognitive models. These models describe the world and anchor the different parts and elements of knowledge one to the other. By anchoring facts in memory as situated knowledge, critical inquiry makes it unnecessary to memorize most facts.

Grey, Knights and Wilmott (1996: 104) describe a process that engages "quality of thinking, not the quantity of what is thought. Relating to, and thereby understanding, knowledge as a dynamic process eradicates the need to memorize it, since like language such knowledge will have become part of everyday usage. In short, we invite students to reduce the distance between themselves and their studies, and give them confidence that this will not mitigate against achieving 'good' results." How shall we do this?

Toward a Critical Practice

In an on-line debate in *Industrial Design Forum,* I once wrote that "Working in research and education implies the right -- and responsibility -- to engage in dialogue with others. The problems we see in our professions today don't come from asking too many questions, but too few. The failure to solve problems generally comes not from asking too much, but from failing to ask enough."

The central theme was the development of learning. "...Students learn by asking questions. The process of inquiry enables them to assemble disconnected fragments of factual knowledge into a robust series of conceptual understandings linked to specific practices. This process leads to the ownership of knowledge. If study is not based on inquiry and thoughtful evaluation of facts, it leads to repeating the assertions of an external authority.

"I encourage my students to learn by considering issues and asking questions. I rarely give answers. I use classroom dialogues as occasions to teach the research and description skills students need to assemble and command their own knowledge. Students who are used to lectures that transmit facts find this approach confusing and disorienting. They start by wanting the right answers. After about six weeks, they begin to realize that many of the issues we pursue can best be understood through inquiry. Their progress from that point on is astonishing.

"New developments in every field make knowledge obsolete rapidly. Some estimate that 50% of what we teach today will be obsolete within five years. Much of what we teach in every field is already obsolete. Some teachers and researchers lack the challenging sense of humility we should feel in ad- [end page 66] [start page 67] dressing new knowledge. I don't mind feeling stupid from time to time, so I've been able to indulge myself in the capacity to learn.

"As a researcher, my strength should rest on what I know and the skills of how to develop new knowledge. As a teacher, my strength should not be what I know, but my ability to help others master skills and take ownership of the knowledge they require. The major skill we impart as teachers is the skill of how to acquire knowledge" (Friedman 1996: unpaged).

In most subjects, in field after field, students are given to believe that knowledge is a stock of stable facts and that progress from ignorance to knowledge is the memorization and possession of a stock of facts. This is not so. Knowledge involves mastery, familiarity, a substantial grasp of that which is known. The word itself implies an active relationship to that which is known: a dictionary, an encyclopedia, a computer contain information that can be defined as "knowledge" but they *know* nothing. In contrast, a human being must *know* to have knowledge, and human knowledge is therefore dynamic.

In contrast, consider the “idiot savant,” the unknowing human being who possess great stocks of fact. The autistic hero in *Rain Man* is an example of an idiot savant: able to calculate prodigiously while unable to relate to the world around him. History gives us many examples, people who could instantaneously compute amazing sums by a pure mental process; people who could name the day of the week on which any day in history falls; people who could repeat huge blocks of text word for word on one reading. This is not the active construction knowledge but the passive repetition of information. These are different meanings of the word. If students are to understand how things are and how they work, they must have knowledge in its most active sense.

Merriam-Webster defines knowledge as “2 a (1) : the fact or condition of knowing something with familiarity gained through experience or association (2) : acquaintance with or understanding of a science, art or technique b (1) : the fact or condition of being aware of something (2) : the range of one’s information or understanding <answered to the best of my knowledge> c : the circumstance or condition of apprehending truth or fact through reasoning : cognition d : the fact or condition of having information or being learned <a man of unusual knowledge> 4 a : the sum of what is known : the body of truth, information and principles acquired by mankind b (archaic) : a branch of learning

“Synonyms: knowledge, learning, erudition, scholarship mean what is or can be known by an individual or by mankind. Knowledge applies to facts or ideas acquired by study, investigation, observation or experience <rich in the knowledge of human nature>. Learning applies to knowledge acquired especially through formal, often advanced, schooling <a book that demonstrated vast learning>. Erudition strongly implies the acquiring of profound, recondite or bookish learning <an erudition unusual even in a scholar> . Scholarship implies the possession of learning characteristic of the advanced scholar in a specialized field of study or investigation <a work of first-rate literary scholarship>“ (Merriam-Webster 1993: 647).

Peter Drucker describes the transformation of information into knowledge in terms strikingly similar to Simon’s description of the conjunctions of science and design: “Knowledge is information that changes something or somebody -- either by becoming grounds for action, or by making an individual (or an institution) capable of different and more effective action” (Drucker, 1990: 242).

Critical inquiry shapes the grounds of effective action by shaping a robust engagement with the empirical world. Rather than accepting authority, one seeks the experience on which to build understanding. This is the first step in scientific discovery. "...An empirical science," writes Herbert Blumer, "presupposes the existence of an empirical world. Such an empirical world exists as something available for observation, study, and analysis. It stands over against the scientific observer, with a character that has to be dug out and established through observation, study and analysis. This empirical world must forever be the central point of concern. It is the point of departure and the point of return in the case of empirical science. It is the testing ground for any assertions made about the empirical world. 'Reality' for empirical science exists only in the empirical world, can be sought only there and can be verified only there" (Blumer 1969: 21-22). [end page 67] [start page 68]

Blumer builds scientific method out of the empirical world, that is, he builds scientific knowledge out of engagement with experience. He does so by using the tools of critical inquiry. To do this, he identifies (Blumer 1969: 24-26) "the more important parts of scientific inquiry, parts that are indispensable to inquiry in empirical science." These can be summarized as: a) possessing and using a prior picture or scheme of the empirical world under study; b) asking questions of the empirical world and converting the questions into problems; c) determining the data to be sought and the means to be employed in getting data; d) determining the relations between data; e) interpreting the findings; f) using concepts.

At every stage in the process, there is a rich relationship between theory and practice, between our conceptualization of the world and the world itself, between our engagement in the world and our understanding of the world, between our tacit understanding and our ability to articulate tacit understanding in conscious knowledge. We can define this conscious knowledge as science: an understanding of how things are and how they work built on fundamental principles (Compton 1930; Simon 1982).

From Critical Inquiry to Complexity

To shape a science of design requires a flexible approach based on rich knowledge and an ability to combine theory and practice. This requirement is the foundation for my argument for a design education based on critical inquiry. It is hopeless to expect a theory-rich practice to emerge from the vocational training developed at the dawn of the century. One may as well expect the radio repair training of the 1950s to prepare someone to manage the integrated information systems of the 1990s. One involved an electrical and mechanical device that runs on vacuum tubes, objects that hardly exist any longer. The other involves a networked electronic information tool linked to a world of similar tools through a complex layer of intermediary programs and systems programs.

The vocational approach to design education is a mechanical trade education aimed at teaching people to operate tools to produce artifacts within frameworks established by custom and the decision of employers. It is a repetitive education based on exercises and certainties. The scientific approach stresses fundamental principles, analytical skill, and a broad overview in addition to specific skills.

In reality, there are few pure vocational approaches to design education today and equally few pure scientific approaches. The great majority of approaches are professional, lodged in the struggle that Compton (1930) described when he examined the program at MIT "to see where training in details has been unduly emphasized at the expense of the more powerful training in all-embracing fundamental principles."

Offering fancy courses with up-to-date titles and topics do not create what Compton called "powerful training in all-embracing fundamental principles." For that, one must begin a scientific design education by teaching students to use the tools of science, intellectual tools, analytical tools, rhetorical tools. These tools must be sharpened and maintained even as students move toward the use and mastery of the physical tools they must manipulate to manufacture the artifacts that will fulfill the goals that change existing situations into preferred ones.

At every step, one must look beyond the complex surface into the heart of a process. One must recognize those moment in which one sees into the key process, finding simplicity without oversimplifying. Economist Brian Arthur, a central figure in complexity theory, points to the simplicity at the heart of complexity in discussing the philosophical influence of his own teacher, Stuart Dreyfus. "He believed in getting to the heart of a problem," says Arthur. "Instead of solving incredibly complicated equations, he taught me to keep simplifying the problem until you found something your could deal with. Look for what made a problem tick. Look for the key factor, the key ingredient, the key solution" (Arthur in Waldrop 1992: 24). This is impossible without a broad view.

Every intelligent design professional in the knowledge era -- graphic designer, information designer, design manager, industrial designer -- must increasingly be a hybrid professional trained with a broad view. These professionals must draw on a number of disciplines to understand the nature of their task [end page 68] [start page 69] in solving specific problems: design leadership, philosophy, psychology, physiology, sociology of knowledge, research methodology, information, strategic design, combining these with the integrated perspective of critical studies and the history of ideas. Is this too broad a range of studies for a single profession? Not in terms of education. It is a matter of practical simplicity in curriculum development. In a design program of eight semesters or more, this means one university-level course per semester plus an integrative program taken in modules and seminars along the way.

The focus of such a program and the view that emerges from it remains design. The context of such a program will be broad enough to enable designers to understand the human beings for whom they design artifacts, the social context within which artifacts will be used. There is an inherent virtue to a broad view, a virtue that builds on the ability to understand the interaction of parts in large systems. This is visible in the development of classifier systems in computer programming or artificial intelligence. Arthur notes the virtue of a broad view where he says, "My experience was that wide systems learned very well and deep systems didn't" (Arthur in Waldrop: 1992: 272).

This breadth and the ability it engenders to cope with uncertainty is equivalent to an ability to accept and make use of information. Uncertainty and information often mirror each other in the development of fit programs under the chaotic conditions designers face today. The "edge of chaos is where information gets its foot in the door of the physical world, where it gets the upper hand over energy. Being at the transition point between order and chaos not only buys you exquisite control -- small input / big change -- but it also buys you the possibility that information processing can become part of the dynamics of the system." (Langton in Lewin 1993: 51).

The ambiguity that exists in complex systems enhances the robust quality that we identify in evolutionary terms as fitness. At the balance point, systems become robust and fit, better able to dominate the environment and better able to reshape the environment in such a way that the environment becomes better suited to their needs (Lewin 1993: 104). Design education based on critical inquiry engages the complexity inherent in the empirical world to achieve its goals. It is more likely to developed fit designers than an education proceeding on the principle of static systems or bureaucratic rules. This affects the outcome of design education in three ways.

The first involves the value of design itself and the employability of design graduates. Organizations which successfully use design to achieve their ends create a stronger adaptive fit to the world around them. This enhances their fitness while competitively reshaping the environment into a fitness landscape suited to their needs. The world becomes increasingly suited to the needs of the successful organization and increasingly hostile to the needs of organisms with differing profiles.

The second is an argument for design as a design science. The more comprehensively designers understand fundamental principles, the more effectively they will further the competitive goals for which they are responsible. A scientific approach to design is more likely to be successful than any other approach. The more comprehensive and richly complex the approach, the more scientific.

The third is an argument for a broad, theory-rich education. If designers are to approach their work as a design science, they require the background that permits them to understand complexity. This means a broad education based on problem-solving and pattern building rather than a narrow education based on repetition, exercise and imitative patterning. It leads, in turn, to a broad professional practice based on problem-solving and pattern building rather than a narrow practice based on repetition, exercise and imitative patterning.

Year after year, design organizations call for the sophisticated and appropriate design practice suited to a complex world. In 1992, for example, the Scandinavian Design Council published a manifesto addressing the broad interactive complex of nature, ecology and human needs. The manifesto proposed a discourse rooted in a natural economics, an awareness of nature, an awareness of human dimensions and an economical way of life. The manifesto called for design in a healthy society "based on sound ethical values; a framework for new ways of life, ecologically and economically sound; built on education; engaged design [that can] visualize, emphasize and realize a powerful message based on ethical principle, ecological balance and economic intelligence ... to influence decisions in private business and in public life; [with] cooperation between designers, producers and users; between invention, industry and the [end page 69] [start page 70] customers they serve" (Scandinavian Design Council 1992: unpaged).

Meeting these challenges with design as defined earlier by Herbert Simon requires a design science with a focus on change management, problem solving, creativity research and transforming information into knowledge. This demands a flexible, principle education rather than an education comprised of the attempt to replicate tasks and assignments. It is an education in which philosophy, psychology, even choreography are as important as mold-making and ergonomic measurement.

The challenge we face today is located in the domain of human interaction and culture theory rather than in technology. The new discipline required for design is as much a branch of the human sciences as a branch of physical science or applied engineering. This new discipline is an influential shadow hidden behind the design professions as they are practiced today.

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Addenda 2005

The History of this Article

Portions of this article were first presented as a paper at *The Challenge of Complexity*, the Third International Conference on Design Management organized by the University of Art and Design Helsinki in August 1995. Later in the year, students at the Institute for Industrial Design at the Oslo School of Architecture invited me to speak about the education industrial design students would need for the future. Not too long after, I spoke on the same subject at the engineering and product design program of the Glasgow School of Art and the University of Glasgow. In Oslo and Glasgow, and at University of Lund and the University of Art and Design Helsinki, a rich series of dialogues and inquiry on several areas of design education emerged at about the same time as a grant from the Norwegian Society for Graphic Design and Illustration encouraged me to look more deeply into the development of a robust paradigm for professionals whose responsibility it is to "[devise] courses of action aimed at changing existing situations into preferred ones" (Simon 1982: 129). This article is the fruit of those dialogues.

Many research projects takes their first shape in tentative and ambiguous form. Scientists generally keep their struggles in the laboratory, presenting finished work full-blown and perfect, ideas bursting forth into the world like Athena from the brow of Zeus. My work often begins in dialogue and genuine dialogue isn't always polished. In inviting me to talk about the ideas presented here, colleagues generously took part in my struggle to articulate a new approach to design education.

If we are to put design on a scientific footing, there is more ground to be won. For the moment, I hope that those who invited me to share my thinking and research will find these ideas useful and recognize their role in shaping this contribution.

About Ken Friedman

Ken Friedman is Distinguished University Professor and Dean of the Faculty of Design at Swinburne University of Technology in Melbourne, Australia. He works at the intersection of three fields: design, management, and art. Friedman works with theory construction and research methodology for design, with a focus on design process and design thinking for value creation and economic innovation. In 1990, Friedman created the first course in strategic design in Europe for the Oslo Business School, one of the first in the world. From 1994 to 2009, he was Professor of Leadership and Strategic Design at the Norwegian School of Management, where he worked on the knowledge economy, culture, and leadership. From 2003 to 2009, he held a research appointment at The Danish Design School and the Danish Design Research Center in Copenhagen.

Ken Friedman has done research in philosophy of design, doctoral education in design, knowledge management, and philosophy of science. He worked with national design policy in Estonia, Latvia, Lithuania, and Wales, and state design policy in Victoria, Australia. He has developed several international research networks and conferences for the design research community. He is an editor of the *Journal of Design Research* and the journal *Artifact* and an editorial board member of *Design Studies*, *Design and Culture*, and the *International Journal of Design*. Friedman is a Council Member of the Design Research Society and the Australian Deans of the Built Environment and Design, and has been an officer in both groups. He co-chaired the La Clusaz Conference on Doctoral Education in Design in 2000, the European Academy of Management Conference in 2006, the Design Research Society Conference in 2006, the Cumulus International Conference in 2009, and the Hong Kong Conference on Doctoral Education in Design in 2011, as well as chairing the Victoria Conference on Design Thinking in 2009.

In 2007, Loughborough University honored Friedman with the degree of Doctor of Science, honoris causa, for outstanding contributions to design research. The award citation by Public Orator Tony Hodgson appears at:

http://www.lboro.ac.uk/service/publicity/degree_days/2007/Summer/Friedman.html

Ken Friedman is also a practicing artist and designer active in the international laboratory of art, design, music, and architecture known as Fluxus. He had his first solo exhibition in New York in 1966. His work is represented in major museums and galleries around the world, including the Museum of Modern Art and the Guggenheim Museum in New York, the Tate Modern in London, the Hood Museum of Art at Dartmouth College, and Stadtsgalerie Stuttgart. The University of Iowa Alternative Traditions in the Contemporary Arts is the official repository of Friedman's papers and research notes. The Silverman Fluxus Collection at the Museum of Modern Art, Archiv Sohm at Stadtsgalerie Stuttgart and the Mandeville Department of Special Collections at the University of California also hold extensive archives on Friedman's work of the 1960s and 1970s.

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