Toward a Marriage of Artistry & Applied Science In the Architectural Design Studio

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Donald A. Schon *is currently Ford Professor* of *Urban Studies and Education in the Department* of *Urban Studies and Planning at Massachusetts Institute* of *Technology. As an industrial consultant,* a *government administrator, and* a *president* of a *non-profit social research consulting organization,* Dr. *Schon has worked* as a *researcher and practitioner on problems* of *technological innovation, organizational learning and professional effectiveness. He was invited in 7970 to deliver the Reith Lectures on the BBC His books include:* Invention and Evolution of Ideas *(formerly,* The Displacement of Concepts), 7963; Technology and Change, 7967; Beyond the Stable State, 7977; Theory in Practice: Increasing Professional Effectiveness, 7974, and Organizational learning: A
Theory of Action Perspective, 7978, *both with Chris Argyris;* The Reflective Practitioner, 7983; *and* Educating the Reflective Practitioner, 7987.

The architectural design studio is an anomaly in the contemporary research university. Its underlying theories of *professional knowledge and teaching are at odds with those* of *other* university *based professional schools. This represents an opportunity: the studio has much to teach other professional schools on the basis* of *its traditions* of *education through coaching and learning-by-doing. On the other hand, what is the place* of *applied science in the studio? This question triggers* a *more general issue about science education* for *the professions. I have suggested how teaching what scientists do, rather than their research results, could influence science teaching in the studio. When considered this way, scientific research and architectural design bear* a *much closer family* resem*blance to each other.*

Introduction

Contemporary professional education consists of two hermetic and disjoint systems. On one side, we find university-based schools of the professions that have adopted, in their pursuit of *aca*demic status, a curriculum modeled on the rigorous ideal of medical education. Following the positivist epistemology of practice that has shaped the modern research university, these schools adhere to a core of systematic, preferably scientific knowledge-first teaching the relevant science, basic and applied, then a practicum in the application of scientific knowledge to everyday practice.' On the other side, we find studios of visual and plastic arts and conservatories of music, dance, and drama. Here, the focus is on the artistry of performance or production and applied science occupies a controversial place, if present at all, on the margins of the curriculum.

Studio and conservatory tend to be freestanding institutions. When contained in a university, they are likely to be marginal, compartmentalized and low in status-the more prestigious the university, the lower their status. Hence, university-based studios and conservatories strive to establish a basis for their teaching in scholarly research. At the same time, because of the growing crisis of confidence in professional knowledge and education, educators are beginning to value the kinds of artistry professional schools are least equipped to teach. Some of them realize they have much to learn from the educational traditions of the studio and conservatory.2

In our bifurcated system of professional education, schools of architecture occupy a troubled, intermediate position.3 Architecture is a hybrid, an occupation concerned with the design of usable structures and an art based on the forms of buildings and the experience of passage through their spaces. Architec*ture's* reliance on older traditions of professional knowledge and education make the university uneasy. And even when architects try to gain a foothold in applied science, they cannot escape their profession's core of artistry; for they are designers and, although ancillary sciences may contribute to specialized design tasks, there is no general science of design. So architectural education still embraces, albeit with ambivalence, the studio traditions that might offer a basis for the renewal of education for artistry in the university-based professional schools.

The time is ripe for re-examining our two systems of professional education; we may be ready to imagine new ways of marrying applied science and artistry. With this end in view, I shall consider the architectural design studio from two points of view, exploring first how it might be taken as an exemplar for the university-based professional schools and second, how it might incorporate applied science.

The Studio as a Reflective Practicum in Designing

In *The Sciences* of *the Artificial,* Herbert Simon4 claimed that designing is fundamental to all professions. But he saw designing as a form of problem solving-in its purest form, optimization thereby ignoring situations of uncertainty, uniqueness and conflict where *instrumental* problem solving occupies a secondary place and problem *setting,* a primary one. In its most *generic* sense, designing consists in making representations of things to be built. In contrast to analysts or critics, designers put things together and make new artifacts. They juggle variables, reconcile conflicting values, and maneuver around constraints-a process in which, although some design products may be superior to others, there are no unique right answers and no moves that have only their intended consequences. With its webs of moves, discovered consequences, and implications, designing is a reflective conversation with the materials of a situation.

Artists make things and are, in this sense, designers. Indeed, the ancient Greeks used the term *poetics* to refer to the study of making things, treating poems as one category of things made. Professionals also make artifacts. Lawyers construct arguments, agreements, and laws; physicians make diagnoses and regimens of testing and treatment; planners construct spatial plans, policies and systems for orchestrating contending interests. More generally, professional practitioners frame problematic situations in accordance with their understandings and methods, and shape the very worlds of practice in which they live out their professional lives.5 As makers of artifacts, they have much to learn from the architectural design studio which is, at its Jest, an exemplar of the process by which one learns to design.

The architectural design studio is a practicum, a virtual world that represents the real world of practice but is relatively free of its pressures, distractions, and risks. Here students learn, by doing, to recognize competent practice, appreciate where they stand in relation to it, and map a path to it. They learn the "practice" of the practicum, its tools, methods, and media. They do these things under the guidance of a studio master, who functions less as a teacher than as a coach who demonstrates, advises, questions, and criticizes. They work with other students, who sometimes play the coach's role. As they immerse themselves in the shared world of the practicum, they unconsciously acquire a kind of background learning of which they will become aware as they move to other settings later on. Our view of the practicum's work depends on our view of professional knowledge. If we focus on facts, rules, and procedures, we will see the practicum as a form of technical training. If we focus on professional knowledge as a way of thinking-"thinking like" a lawyer, teacher, or manager, for example - we will attend to the ways in which students learn to reason their way from general principles to concrete cases. If we focus on the kinds of inquiry by which practitioners sometimes make new sense of uncertain, unique, or conflicted situations-the process I call "reflection-in-action”- then we will notice how, in a practicum students learn to construct and test new categories, of understanding. It is important to add that the third kind of practicum may depend on the first two. Perhaps we learn to reflect-in-action by learning first to apply standard rules, facts, and operations; then to reason from general rules to concrete cases; and only then to develop and test new forms of understanding when familiar ways of thinking fail.

Practicums of the third kind exist in the second system of professional education, to which I have referred above: the deviant traditions of the studio and conservatory. Practicums are sometimes also found in apprenticeships or-less often, and usually without formal legitimacy in the peripheral regions of the normative curricula of the professional schools. I call these practicum "reflective" because they aim at helping students learn to become proficient in various kinds of reflection-in-action and because, as we shall see, they depend for their effectiveness on coach and student entering into a kind of communication that is, at its best, a dialog of reciprocal reflection-in-action.

From my participation in studies of the architectural design studio, I have drawn a description of conditions and processes inherent in any reflective practicum.6

To begin with, I have observed that students must begin designing before they know what it means to do so. They quickly discover that their instructors cannot tell them what designing is, or that they cannot learn what their instructors mean by what they do say, until they have plunged into designing. Hence, in the early stages of the design studio, confusion and mystery reign. Yet in a few years or even months, some students begin to produce what they and their instructors regard as progress toward competent design. Coach and student finish each other's sentences and speak elliptically in ways that mystify the uninitiated. They seem to have achieved a convergence of meaning.

They make this transition-those who succeed in doing so-by joining in a dialog of words and actions. The student reflects on what he hears the coach say or sees the coach do, and evinces his or her understandings in further performance. The coach, in turn, interrogates the student's performance in order to discover what it reveals in the way of knowledge or ignorance, and considers what further demonstration, questioning, advice, or criticism might help the student.

A good coach must be able to demonstrate designing and describe it, particularizing what he or she does or says to fit the student's momentary confusions, questions, difficulties, or potentials. So the coach improvises, drawing on his repertoire, reflecting on his own spontaneous performance, conducting on-the-spot experiments in design and communication. In this process, the coach moves up or down the ladder of reflection, shifting from designing to description of designing, or from description to reflection on description, and back again to designing.

The student may reflect on her own spontaneous performances in order to discover what she already knows that helps or hinders her learning; and the student tries, through reflective imitation, to construct in her own action the features essential to the coach's demonstration. The student tries to strike a balance between taking responsibility for self-education in designing, and remaining open to the coach's help. For the student as for the coach, two kinds of practice are involved in the practicum: the substantive designing the student tries to learn and the reflection-inaction by which she tries to learn it.

The coach assumes that an initial instruction will be sufficient to get the student to do *something.* This initiative gets the dialog started and provides a first occasion for feedback, which the student is very likely to find confusing or ambiguous. Nevertheless, however incomplete or mechanical the initial moves may be, the student begins to learn what it feels like to carry them out. In Wittgenstein's potent phrase, the student learns the meaning of the operation by performing it. And this performance allows the coach to give a new instruction or demonstration in order to correct the error discerned. Or the student, although unable to say why, does something that feels wrong, and the coach provides a way of explaining it. So the stage is set for a continuing dialog of reciprocal reflection in and on action, within which the student increasingly grasps what it means to design and thereby increases in ability to participate in the dialog.

The paradox of learning to design-that the student cannot be told about it ahead of time in any way she can understand, but must begin to do it in order to learn what it is-carries with it a predicament. The plunge into doing, without knowing what one needs to learn, provokes feelings of loss. The student feels a loss of control, competence, and confidence and, with this, a sense of vulnerability and dependency. The coach must accept being unable at first to tell the students about designing and must cope with their reactions to the predicament in which they have been placed.

Occasionally, a student reveals an ability to enter into an instructor's view of designing, secure in the ability to break it open later on. More often, the student's initial sense of vulnerability turns to defensiveness, and the learning predicament may become a learning bind. This may happen in the classroom, as well, but tends to be masked there by conventional habits of lecturing and note-taking. In a reflective practicum, the coach's ability to avoid or dissolve learning binds depends on the behavioral world he helps create with the students and his ability to foster a relationship open to inquiry.

In order to be credible, a reflective practicum must become a world with its own culture, including its own language, norms, and rituals. Otherwise, it risks being overwhelmed by the academic or professional cultures that surround it. But if it succeeds too well in establishing its own culture, isolated from the larger worlds of university and practice, then it may become, in Hermann Hesse's phrase, a mere "glass bead game."

A reflective practicum is unlikely to flourish as a second-class activity. The professional school must give it high status and legitimacy, or it falls prey to the dilemma of Nathan Glazer's "schools of the minor professions"7 where students are forced to choose between low status "relevance" or high status "rigor." Coaches must be first-class faculty members, and the process of coaching and learning must become central to the intellectual discourse of the school.

In the university-based professional schools, prevailing models of professional knowledge and classroom teaching are bound to be hostile to the creation of a reflective practicum like the architectural design studio, where overriding importance is attached to the process of coaching students in learning by doing. On the other hand, educators brought up in the tradition of the architectural design studio are likely to be hostile to the introduction of applied science and scholarship. In both cases, the challenge is to create a workable marriage of artistry and applied science, reflective practicum, and classroom teaching.

Applied Science in Studio Education

There is a very long list of applied sciences that at least some educators have thought architects needed to know. Among these are energy-related engineering and design, soil mechanics, structural engineering, building materials and technologies, geology, topography, solar engineering, acoustics, wind effects, earthquakes and earthquake hazard reduction, building economics, building finance, building diagnostics, urban development and design, law as it applies to architecture and building, the dynamics of groups and team functioning, the anthropology of architectural practice, urban politics, architectural history, the structure of the building industry, and computer science.

Each of these fields of study has been introduced into the curriculum of at least one architectural school, using one of several strategies of introduction. Some schools have established rudimentary courses in applied science as a preliminary to studio experience. Specialized studios, like Ralph Knowles's solar envelope studio at the University of Southern California, have focused on a particular body of knowledge. Larger studios, like the "Total Studio" taught in environmental design at MIT, have incorporated lectures or mini-courses in particular fields of knowledge at key points in the development of a studio project. Resources for technical assistance in special fields have been created and made available to students for their *ad hoc* use, with or without recourse to computer environments.

These strategies reflect different approaches to the problem of introducing fields of special knowledge into an architectural curriculum. Those who have introduced small chunks of applied science into studio projects, mindful of the problem of motivating students to learn, have tried to teach specialized knowledge when students are most likely to see the need for it. Those who advocate a base of applied science prior to studio experience argue that knowledge must be conveyed prior to its use, and that the extraordinary demands of the studio make students resist learning material whose utility is not immediately apparent to them. Those who have created knowledge-specialized studios want to present a critical mass of knowledge in a context where its implications, for designing are immediately apparent.

Several of these problems - having too much to teach, making students receptive to knowledge-are by no means peculiar to schools of architecture. What is both more special to architecture and more fundamental is that the teaching of applied sciences tends to be accompanied in the studio by a view of knowledge and a mode of teaching that are very different from the epistemology and pedagogy built into the research university.

Students truly responsive to the messages of the design studio, immersed in learning to think like designers, are often puzzled by, skeptical about, or downright hostile to the various forms of applied science some of their professors feel they need to know. And these students' attitudes are, in many cases, mirrors of the attitudes of influential design instructors. The difficulty of making a productive marriage of applied science and studio education is not only a matter of overload and logistics, or quirks _of style, habit, and personality; rather, it goes to the heart of the discrepancies between forms of knowledge and teaching honored in the university and the studio's .epistemology of practice, its emphasis on the artistry of designing, and the basic assumptions that go into its version of the reflective practicum - discrepancies that underlie architectures marginal position in the university. Hence, the problem of marrying studio education with the teaching of applied science is central not only for architectural education *per se* but for architecture's future role in the university.

I shall consider this problem in the light of four ideas which are as important to science teaching in general as they are the special case of science in the architectural studio:

1. *Science* as a *body* of *research results vs. science* as a *method* of *inquiry.*
When we teach science, not only to architects but to other kinds of students, we tend to present it as a body of facts, theories, and techniques, in short, as a product of scientific research. Moreover, the usual way of presenting science in the classroom, the one also favored by scientific journals and texts, presents it in the declarative mode, in sentences as unambiguous as possible, on the basis of a retrospective view that justifies what scientists have inferred from their observations, experiments, and analyses. The research processes that led up to these products tend to remain hidden.

Science looks like a very different enterprise depending on whether one encounters it in the form of its results astringent, distanced, maximally objective-or in the form of its before-the-fact, processes of inquiry. These "retrospective" and "prospective" views might also be called "justificatory" and "exploratory," or "analytic" and "phenomenological," depending on the features chosen for emphasis. The important point is that the teaching of science, to architects and others, is always under a certain *view* of science-a view shaped by a wish either to meet prevailing standards of evidence, argumentation, and elegance of presentation, or to be faithful to the experience of before-the-fact discovery and invention.

2. *Learning* theories *about phenomena vs. getting* a *feel* for *the behavior of phenomena.*
When science is presented in a retrospective way, the symbolic generalizations used to describe research results do not convey the feel of the phenomena they describe, and do little to help us recognize them when we see them. I am reminded of a story a chemist colleague of mine used to tell. He cited a journal article about the instability of certain hydrogen peroxide compounds. Reading that article with its equations and sparse analytic arguments, one would never guess that the data informing it had been produced when the back of a plant blew out.

The modes of experimentation peculiar to scientific inquiry are characterized by errors, anomalies, uncertainties, and confusions-all of which are masked by the neat, self-contained formulas and formal models typical of retrospective presentations of science. For this reason, some scientific educators are passionately devoted to the proposition that students must be exposed to hands-on laboratory experience. One of these educators, a physicist at MIT, put it this way:

> "In physics, there is some kind of physical interaction going on, to which some instrument responds, and you have to understand every step of it. The instrument is part of it . . . You take a curve with zero input, you get an experimental curve and you convolute those two together, point by point, and you know that you're doing the right thing! Or if you have doubts about it, you can understand. Maybe something different happens when you turn off the current. What could be happening?
>
> "If you make a fast Fourier Transform, where will you ever think about this? Typically, you're supposed to turn off the magnetic field to get your zero curve. . . and I say, 'Are you sure the magnetic field is zero? Did you degauss the magnet?' Now, if you don't get through some kind of procedure like this, you're not going to see that."8

In this physicist's view, it is crucially important for students to experience how established scientific theories usually do *not* precisely fit experimental data.

When scientists occasionally describe their encounters with phenomena, their descriptions are often poetic. For example, this is Evelyn Keller's report of the geneticist, Barbara McLintock's, description of her encounters with the chromosomes of maize:

"I found that the more I worked with them, the bigger and bigger (they) got, and when I was really working with them I wasn't outside, I was down there. I was part of the system. I was right down there with them, and everything got big. I even was able to see the internal part of the chromosomes-actually everything was there. It surprised me because I actually felt as if I were right down there and these were my friends."9

When science is taught to students of the professions as a method of inquiry rather than as a body of research results, it can be clearly seen to resemble what skilled practitioners do in their own on-the-spot research. For skilled practice is, in its own right, a form of experimentation with its own discoveries of patterns in phenomena, and its own generation and testing of hypotheses.

Significantly, even when a professional practitioner makes practical use of scientific principles or techniques, he must conduct an intermediate form of on-the spot research. So, for example, physicians speak of the large number of patients whose cases are "not in the book," and of the need to conduct experimental inquiry in the office or clinic in order to modify or combine standard diagnostic categories or even, on occasion, to evolve wholly new categories.

More specifically, the prospective view of science reveals a kind of inquiry that is close in spirit to designing. For design is itself a kind of experimentation, though one that bears only a family resemblance to experimentation in a scientific laboratory. I n *The Reflective Practitioner* I described three functions of experimentation in designing: exploration, move-testing, and hypothesis-testing.10 I proposed that whereas the logic of hypothesis-testing is the same in designing as in science, the overall logic of experimentation in design is unique. Here a single design move may bear the burden of all three functions. For example,
a designer confronted with a "screwy site"-one that offers no initial coherence for design-may choose to impose on it an arbitrary geometrical discipline, testing whether the imposed geometry carved into the slope may then "work with" the contours of the buildings. In such a process, the designer explores the properties of the site, tests a move (the imposition of the geometry), and tests an underlying hypothesis about the potential fit of the modified contours of the slope to the shapes of the buildings.

It is when we see science and art only retrospectively, through their results, that art and science seem most disjoint. When we are exposed to their before-the-fact processes of inquiry, they seem much more like each other.

Many scientists readily admit that when they teach, they don't teach what they actually do. So most students "learn science" without learning what it is like to *do* science. This is true not only of the teaching of science in architecture but of science teaching in all professional education. For example, a former Dean of the Albert Einstein School of Medicine spoke with feeling, in our discussions together, about his vain attempts to get biologists on his faculty to teach medical students by engaging them in the process of doing biology.

Clearly, it is difficult to teach science in a prospective way. In order to do so, one would have to solve important intellectual problems of educational design especially when students begin with relatively impoverished understandings of science and there is limited time available for teaching.

Yet there are interesting examples of science teaching on which to build. In some of these, teachers have made productive use of computer environments to create systems that short-cut the drudgery often involved in running experiments. In the Civil Engineering Department at MIT, for example, Professor John Slater has developed a computer program called GROWL TIGER as an aid to the teaching of structural engineering. With GROWL TIGER, a student can represent a structure like a truss or a frame as a pattern of lines on the computer screen.

The student need only set the geometry of the structure and select the dimensions of its members and the type of steel to be used. The student can then ask the computer to analyze the forces, moments, and deflections, and the program will display them graphically on the screen. In order to provide a better feel for the impact of the loading, the stiffness of the structure, and the resulting deflections, the program can display deflections moving from zero to the full range. After one iteration of design and analysis, the student can check whether the structure behaves within the allowable tension in the beams and the allowable deflection of the structure. The student can then decide to change the geometry, the loading, or the stiffness, and redo the analysis in a matter of seconds.

When students speak of their experiences with GROWL TIGER, many often refer, first of all, to their pleasure at being spared the drudgery of carrying out lengthy calculations. But they also speak of the experience of *visualizing* the effects of loads on the structures they design. They observe that their ability to make many quick iterations of design and analysis gives them a feel for the behavior of structures which they do not get from exposure to theory in lectures and texts. They sometimes adopt an apologetic tone when they note that, with GROWLTIGER's help, they have come to know-structures in a very different way, even though they had passed an introductory course in statics and were supposed to know the basics already.

And some students, perhaps the more talented among them, spoke of the surprises they encountered and the puzzles they had to solve when the structures they drew turned out to behave contrary to their expectations. As one student put it:

"I applied a wind load and I saw it lean a little and I noticed that because the building was so vastly cantilevered, only the middle third of it was supported. I saw the continuity of how it would have to behave if it weren't going to fracture and fail catastrophically. . . (I saw that) if I wanted to get rid of some deflection in a floor girder, I could stiffen up the wall columns... (then I saw that) by making some columns a little bit wider *without necessarily changing the weight or even lowering the weight* I could make the building stiffer."11

Just such a feel for the phenomena (in this case, structural behavior) is what designers need, even more than they need to know the relevant equations-a feel, for example, for the behavior of solar envelopes, soils and foundations, the effects of wind on buildings, or the characteristic phenomena of building economics and finance. These are what scientists and engineers are fond of describing as their "intuitions." The approach to science teaching illustrated by GROWLTIGER seems to work by helping students develop such intuitions, while at the same time it exposes them to processes of design, experimentation, analysis, and observation that closely parallel the before-the-fact processes of science.

3. *Prototypes, exemplars,* and *precedents* in *scientific inquiry and architectural designing.*

In his "Second Thoughts on Paradigms," Thomas Kuhn describes how students learn physics.12 He believes that they do *not* proceed by first grasping symbolic generalizations, which they later learn to apply. Rather, he suggests,

"The student discovers a way to see his problem as like a problem he has already encountered. Once that likeness or analogy has been seen, only manipulative difficulties remain."13

Typically, a beginning student of physics learns to solve many canonical problems-like figuring out the acceleration of a ball rolling down an inclined plane.

"In the course of their training a vast number of such exercises are set for them, and students entering the same specialty regularly do very nearly the same ones, for example, the inclined plane, the conical pendulum, Kepler ellipses, and so on."14

These concrete problems with their solutions are what Kuhn calls "exemplars," a community's standard examples. Starting with such exemplars, the student must learn to see other problems as analogous to them, and then, in Kuhn's words, "an appropriate formalism and a new way of attaching its symbolic consequences to nature follow."15

If Kuhn is right, beginning scientists learn their trade by familiarizing themselves with prototypes by reference to which they learn to see other problems as similar, before they can say "similar with respect to what." The implications of Kuhn's view for science teaching are clear: this is how students learn science regardless of the pedagogies by which they may be "taught" it. But Kuhn's thesis also has important implications for the connections between doing science and designing, learning to do science and learning to design.

In our studies of design knowledge and reasoning among practiced designers, William Porter and I have been struck by the importance of what we have labeled "types," though in a sense somewhat different from the ordinary use of this term in architecture. Like other observers of designers - for example, Arnheim16 and Habraken17 - we have noticed that types playa variety of crucial roles in architectural designing.18 We have thought of types as particulars that function like general categories; or, to put the matter differently, general categories that have the fullness of particulars. Types, in this sense, seem to function both as holding environments for design knowledge and as generators of leading ideas that guide whole sequences o. design moves.

As we have examined the protocols of practiced designers at work on the same design exercise, we have identified several sorts of types, each with its own characteristic functions. There are, for example, "functional building types," like "branch library" or "suburban site." These serve as reservoirs of commonplace knowledge on which designers draw to fill in the intermediate premises of their design reasoning. 'There are "references"-for example, "a Richardson library"-that serve, often under special conditions, as generators of strings of design moves. There are spatial Ges*talts-for* example, a view of a particular geometry as" a middle area with three pods attached to it"-which form the essential background on which the designer works, and in relation to which he or she sets the problems to be solved. And there are, finally, what we have called "experiential archetypes." These might be illustrated by a cave, a movement from light to dark to light, an entrance "like a pair of outstretched arms," or a concave entrance that" captures you and draws you into the heart of the building." These also function as generators of leading ideas, but they are especially prominent in zones of designing that architects sometimes describe as "art" or "poetry." Experiential archetypes seem to be called upon when the mundane task of making a building work presents itself as one of particular difficulty.

It would take a good deal more space than is available here to do justice to our observations and speculations about the function of types in architectural designing. What I can suggest, however, is that it may be fruitful to think further about the roles of prototypes, exemplars, and canonical examples in learning both to design and to do science. If types do function as holding environments for design knowledge and generators of leading ideas, then studio instructors may wish to focus more explicitly on the processes by which students become familiar with types and their functions, and build up repertoires of types on which they draw in their designing. It may be interesting, then, to explore how architectural types may be enriched through linkages to exemplars in the applied sciences-how functional types of buildings, for example, may be enriched to include connections to the behavior of structures and their responses to environmental stresses. Moreover, recognition of the functions of prototypes and canonical examples may help us to make more fruitful connections between students' ways of learning to do science and their ways of learning to design.

4. *Kinds* of *thinking peculiar* to *skilled scientists and skilled designers.*

In the department where I now teach, there was in times gone by a social scientist-himself a renegade architect who declared that "architects don't think" and refused to allow them in his classes.
In my own early teaching at MIT, before I learned to appreciate the kinds of thinking that go into skillful designing, I was struck by how hard it seemed to be for many students of architecture to "think" as *I* understood thinking-to make clear verbal arguments and reflect critically on them in the light of internal consistency, evidence, and disconfirmability.

There do seem to be important differences in habitual patterns of thinking among graduate-level students of architecture and students of the physical or social sciences. Students who learn in the studio how to think like a good designer tend not to learn how to man age the verbal argumentation and criticism characteristic of social science and policy analysis. And the reverse tends also to be true: an ability to construct and criticize verbal arguments is no guarantee of skill in designing. To the extent that this observation holds true and it is likely to be controversial-there are important implications for both studio education and the studio's place in the larger university. How robust is this difference in thinking? How wide spread? How significant for students' later practice?

I have worked, on occasion, with architects engaged in writing theses for an advanced degree, and have tried to introduce them to what ought to be a helpful metaphor: designing and building an argument. For arguments must be constructed; one must discover, through exploration and testing, what their fundamental structure might be; it is helpful to sketch them before developing them fully; and as one tests them, one often gets a salutary surprise (as in architectural designing) which leads to reframing the argument and, sometimes, to a new idea.

But for all these tempting analogies, it seems to be extraordinarily difficult for architectural students to cross over. I am not sure why. Perhaps the difficulty has to do with differences in media, or with the powerful attraction of architectural fashions, or with the countervailing mystiques of architecture and social science. However this may be, some students do manage to cross over, from either side of the divide, and make themselves formidable exceptions to the general pattern.

One student interviewed in a study of computers and education at MIT offers a particularly illuminating example of what it means to carry over skill in designing from architecture to other domains. Originally educated as an architect, this student has become proficient at computer programming. He believes that his way of programming owes a great deal to his architectural training, and he has reflected on the analogies between the two practices. "Now basically," he says, "what I do first is. . . try to write [the program] as quickly as possible. Without thinking. When I do it, I just write the steps it would take my brain to do it. That's very crude. And I don't usually keep those programs for the most part, because those are very inefficient programs. And then I go swimming. . . or whatever, and while I do that, I think about the program: how can I make it more efficient? . . . and I say, 'How can I make the computer do this in such a way that it will take me 10 minutes to write the program? How can I make sure the computer doesn't overwork? How can I drop possible bugs?' "This is what I call catching the program. Just the first catch. I don't think anybody has told me that. But that is basically what I've learned by doing it. Most of the things I do are like that. I first do a sketch. . . I like architecture, and was pursuing a degree in architecture, and the first thing that you learn there is just draw a sketch. So that's what I do in everything. . ."19

Might it be possible to help students make the sort of crossover this student made for himself (doing it, as he says, because "it comes to me naturally")? If it were possible, there might be important consequences for broadening studio education and bridging between it and education in physical and social science. Certainly it will be important, in pursuing this question, to explore new ways of helping students reflect on their designing. There may be some particular merit in exploring computer programming as a transitional activity linking architectural design to verbal argumentation.

Conclusion

The themes mentioned in the preceding pages seem to me to support a single proposition: the apparent disjunction between science and architectural design, like the more general split between the sciences and the arts, has its roots in a particular view of science. If students of architecture come to experience science as a form of prospective inquiry-one that brings them into direct contact with the phenomena, methods of experimentation and canonical examples of before-the-fact science-then learning science is likely to have a very different and much more powerful meaning for them. Learning to do science, like learning to design, occurs most favorably in the context of a reflective practicum; the paradox, predicament and dialog of coach and student inherent in learning to design are mirrored in learning the skills of scientific inquiry. What is more, if we learned this way of teaching applied science to architects, we would help them to make fruitful connections between characteristic exemplars and ways of thinking on both sides of the divide. For science itself is a design like practice, though that fact is hidden from us when we see only the results of science and have no experience of its processes. The positivist epistemology of practice underlying the modern research university emphasizes a retrospective view of science as a body of facts, theories, and techniques which professions like architecture are meant to apply. But when we experience science and architectural designing as before-the-fact inquiries, we become aware of their deep similarities and potentials for reciprocal influence.

Of course, the boundaries between these design-like practices are by no means transparent; transfer of learning across them is neither easy nor inevitable. What is in question, rather, is an attitude toward learning which casts a very different light on the place of the arts, architecture among them, in the larger university, and bridges the chasm that separates our two systems of professional education.

Architecture's marginality in the university stems both from the retrospective view of science that has long prevailed in the university, and from the fact that architects themselves have tended to keep their own processes of inquiry private, tacit, and sometimes even mystical-have tried, perhaps defensively, in order to emphasize their differences from other fields, to protect themselves from reflection on their own skillful practice.

1 See Schein, Edgar *Professional Education* McGraw Hill (New York) 1972.
2 I have developed this argument at some length in Schon, Donald A. Educating *the Reflective Practitioner* Jeey Boss (Son Francisco) 1987.
3 See Schon, Donald A. *The Design Studio* Royal Institute 01 British Architects Press (london) 1986.
4 Simon, Herbert *The* Sciences *of the Artificial* MIT Press (Cambridge. MA) 1976
5 The line of thought developed here owes a great deal to the "constructionism" advanced by the philosopher Nelson Goodman, in his *Ways of World* making Hocke_ (Indianapolis, IN) 1978.
6 I refer here to the study of architectural education directed by Maurice Kilbridge of Harvard and William Porter of *MIT* in the mid-1970's, and to subsequent studies conducted at MIT in the Design Theory and Methods Group.
7 Glazer, Nathan "The Schools of the Minor Professics," Minerva 1974
8 Interview with on MIT physicist, quoted in a study conducted by Schon, Donald A. and Sherry Turkle Proied *Athena* at *MIT,* MIT, mimeo, 1988
9 Keller, Evelyn Fox A *Feeling* for *the* Organism W. H. Freemon and Company (New York) 1983
10 Schon, Donald A. *The Reflective* Proctitioner: *How* Profe*ssionals Think* in Action Basic Books (New York) 1983
11 Quoted from Schon and T urkle, op. cit.
12 Kuhn, Thomas *The Essential Tension* University of Chicago Press (Chicago, Il) 1977
13 ibid., p. 305
14ibid.,p.305
15 ibid., p. 306
16 Arnheim, Rudolph *Visual Thinking* University of California Press (Berkeley, CA) 1969
17 Habroken, John The Appearance *of the Form* Atwater Press (Cambridge, MA) 1986
18 Schon, Donald A- "Designing: Worlds, Rules and *Types," Design Studies* (Milton *Keynes,* England) 1988
19 Schon and Turkle, op- cit.