Conceptions of the Engineering Design Process: An Expert Study of Advanced Practicing Professionals

Susan Mosborg, Robin Adams, Rebecca Kim, Cynthia J. Atman,
Jennifer Turns, and Monica Cardella
Center for Engineering Learning and Teaching, University of Washington

*Abstract***.** *Published models of the engineering design process are widely available and often illustrated for students with a block diagram showing design as sequential and iterative. Here we examine experts' conceptions of the design process in relation to a model synthesized from several introductory engineering textbooks. How do experts' conceptions compare? What might they see as alternative accounts? We present preliminary results from an investigation of practicing engineers (n=19) who were asked to think aloud while reading a description of this "textbook" model, as well as draw their idea of the engineering design process and choose descriptors of design. Only 3 participants were found to have a view in major disagreement with the model, yet 7 drew alternative types of diagrams, and the experts as a whole emphasized problem scoping and communication. We focus especially on the case of one engineer who commented extensively on communication, articulating a view of engineering design as open, multi-participant, and multidisciplinary, with implications for how to conceptualize expertise in engineering problem solving.*

Engineering textbooks have traditionally introduced students to engineering design by way of a block diagram. Although these diagrams vary slightly from one textbook to the next, the iconic diagram encloses each stage of the process in a block and depicts flow through the stages using arrows, typically double-ended to signify iteration between phases. Figure 1 is one example of the linear depiction of the engineering design process popularized in textbooks over the last several decades (Dixon,[1] as cited in Bucciarelli,[2] p.93). The number of stages in these diagrams has ranged from a few to several dozen (see, for example, Woodson[3]), depending on the detail and complexity with which the design process is rendered. In a content analysis of seven introductory engineering design textbooks conducted in 1995, Atman and her colleagues[4] synthesized the texts' depictions into a six-step model: 1. Problem Definition, 2. Information Gathering, 3. Generation of Alternative Solutions, 4. Analysis/Evaluation, 5. Selection, and 6. Implementation/Communication.

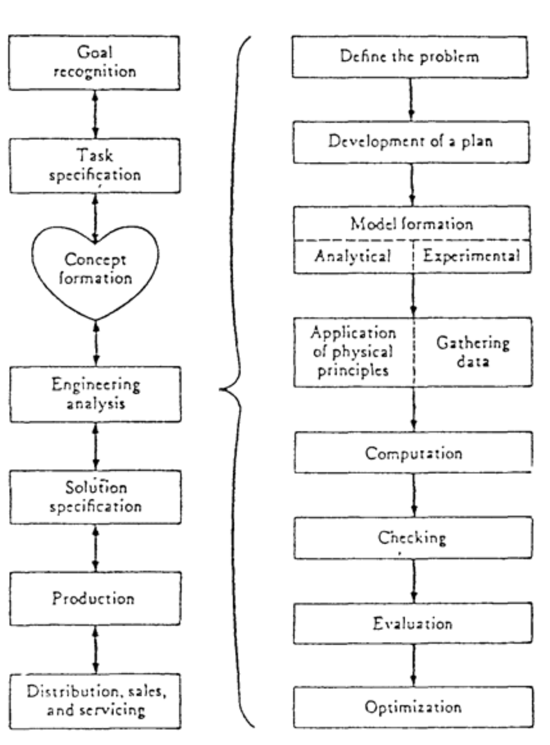
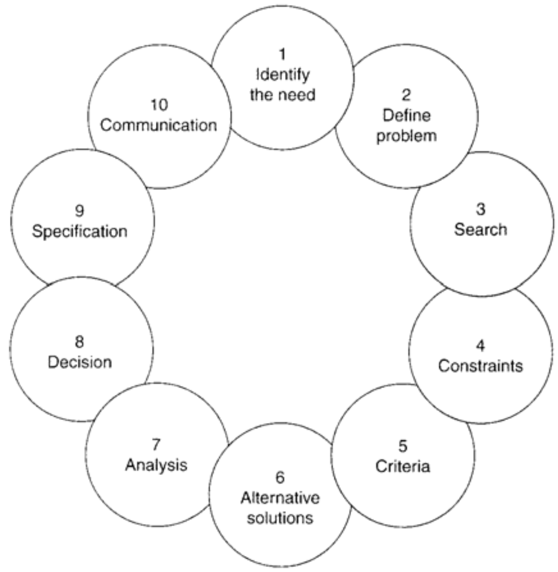


Figure 1. Block diagram of the design process reproduced from Dixon,[1] p. 11, as cited in Bucciarelli,[2] p. 93. Reproduced with permission.

In recent years, the overall presentation of the engineering design process in engineering textbooks has undergone subtle changes. While the majority of model diagrams remain linear, some departures can be seen—for example, cyclical diagrams in textbooks by Burghardt[5] (p.33) and by Eide, Jenison, Mashaw, and Northrup [6] (p.81) (see Figure 2). The circular arrangement of steps does not fundamentally alter the steps' content, but underscores the central role of iteration in design. While the nonlinear, flexible nature of design is long-established,[7] it is increasingly foregrounded in introductory textbooks, along with communication and concurrent engineering. Teamwork is presented as both an asset and reality of work today. Burghardt describes the teaming of everyone involved in the production of an artifact as "one of the newer characteristics of the modern engineering company" (p.35). Undergraduates are encouraged to anticipate addressing the entire life cycle of production, actively collaborating with other stakeholders in design, a strategy Ullman[8] suggests improves upon the traditional but inefficient "over-the-[cubicle]-wall method" of the past (p.10), in which engineers performed one leg of a relay. An emphasis on teamwork, communication, and concurrent engineering are also echoed in the current ABET[9] accreditation criteria for engineering education programs, as well as in press coverage of design innovation firms such as IDEO.[10]

Figure 2.3



The design process is iterative in nature.

Figure 2. Cyclical diagram of the engineering design process (Eide et al.,[6] p. 79). Reproduced with permission.

Despite these shifts in focus, today's graphical representations of the engineering design process are consistent with the traditional models from decades ago. The general stages of design, while sometimes difficult to draw boundaries between, remain slight variations on a consistent theme. Block diagrams, notes Bucciarelli[2] (p.92), plausibly capture the design process as academics and practicing engineers alike "believe [it] ought to work." The resilient block-flow diagram appears to be a dominant representation of engineering design to this day (see, for example, Haik,[11] Kemper & Sanders,[12] Pahl & Beitz,[13] and Ullman[8]).

It stands to reason that some semblance of this block-flow model is initially adopted by engineers during their undergraduate engineering program. Not surprisingly, it has been found uncharacteristic of pre-engineering novices. Based on their experience asking undergraduates from a variety of majors to draw concept maps of design, Newstetter and McCracken[14] report that novices tend to conceptualize design as an artistic, creative process. The students' concept maps the analysts examined focused on idea generation and brainstorming, consistent with novices' tendency when designing to pursue one "good idea" rather than consider several alternatives (see also Purcell & Gero[15]). According to Newstetter and McCracken, the novice conception that design is "a blaze of creative light that strikes some and not others" (p.70) may explain why the novices in their study, when asked to choose from a list of words those that most and least describe the activities of design, chose iteration and evaluation—two prominent themes of the iconic block diagram—as among the *least* relevant descriptors of the design process.

Moore and Atman et al.[4] also explored the design process from the beginning engineering students' perspective and found little evidence students were heeding the iconic block-flow model. Their study found that, contrary to the design approach of effective designers, novices tended to dive into a design problem without a clear plan or direction for how to solve it. When given an open-ended design problem, students neglected to recognize as priorities either the generation of alternative solutions or such “real world” steps as identification of need and implementation. Overall, students appeared unaware of several established steps in the design process model. In a related study, Atman and her colleagues[16] found that engineering freshmen were less likely than engineering seniors to progress to later steps in the model, spending less time in activities such as evaluating solutions.

Clearly, the block-flow model does not simply capture a general problem solving strategy subscribed to by people of any trade. Yet, to what extent do experienced engineers subscribe to and use the model? Could it be a mere blip on the screen of practicing engineers’ conceptions of design as they progress through their careers—like a youngster’s coat, worn for awhile, then outgrown and discarded? Conversely, is it clung to, refashioned and elaborated? Or is it never much used in the first place? Certainly, critics have questioned the relevance of the model to real-world engineering practice. Ferguson,[17] for example, has challenged the ability of the block diagram to adequately reflect the contingent nature of design. Despite being an accepted model for how design should work, he argues, if blindly used as a roadmap, the block diagram may mislead novices into thinking design is a process completely under their control. Bucciarelli[2,18] sees the block-flow model as only partial explanation of the design process, reflecting design’s “object-world” aspect of formally measured work with physical materials, but not its “process-world” aspect of narrative experience and social interaction.

In this study, we explore expert engineers’ conceptions of the design process and its relation to the block-flow model. Although a number of studies have analyzed verbal protocols of expert engineers saying aloud their thoughts as they engage in a design task (for a review, see Cross[19]), or observed expert designers in their natural settings (for examples, see Bucciarelli[2,18]), few studies, if any, have directly investigated expert engineers’ conceptions with elicitation techniques such as asking participants to draw a concept sketch or comment on one (at least we have not been able to find any such studies). The ethnographic and verbal protocol literature does provide insight into designers’ conceptions; Petre,[20] for example, observed and interviewed innovative design teams who described a number of purposeful strategies they use to “get out of the box” of familiar thinking and found they deliberately followed systematic practices to foster inspiration and innovation. Here, however, we take advantage of elicitation techniques less frequently used in studies of engineering expertise. We see these kinds of investigations as an important complement to the existing ethnographic and verbal-protocol literature. Each type of study is needed if we are to understand the underlying conceptual models that guide the moment-to-moment thinking and heuristics of expert engineers.

The data analyzed was collected as part of a larger verbal protocol study, one part of a 5-year project investigating engineering design expertise across three concurrent activities: 1) studying practicing professionals’ design performance, 2) developing a framework for characterizing learners’ growth toward design expertise, and 3) demonstrating implications in teaching practice. Our aim is not to critique design process models per se, but to use the iconic engineering model as a point of departure for contributing to theory of design expertise. In this paper, we present an initial portrait of experts’ conceptions of the design process that, we hope, will provide a useful mirror for examining engineering curricula, revealing points of potential congruence and discrepancy between how experts think about design and what curricula aim to help students understand. It will also help establish a basis for expert-novice comparisons that highlight major conceptual transitions to be promoted for growth toward expertise.

Methods

Participants. Nineteen engineers from a variety of engineering disciplines and 1 landscape architect participated in the study. All were advanced practicing professionals. As defined by their undergraduate major, 9 participants were mechanical engineers, 3 were electrical engineers, 2 were civil engineers, 2 were industrial engineers, 2 were material sciences engineers, and 2 were systems engineers. Among the engineers, mean number of years experience in the field was 19 (range 7-32 years). Eight of the engineers had master's degrees in a subfield of engineering, and an additional 4 had Ph.D.s. Fourteen of the engineers were white males, 3 were Asian / Pacific Islander males, and 2 were white females. The landscape architect was a white male with 13 years experience in the field and an undergraduate degree in landscape architecture. The greatest portion of participants (9 of the 19 engineers) were currently employed in large corporations with over 10,000 employees, but others were from small to medium-sized firms and as a group had previously worked as engineers, on average, at two other organizations of various sizes.

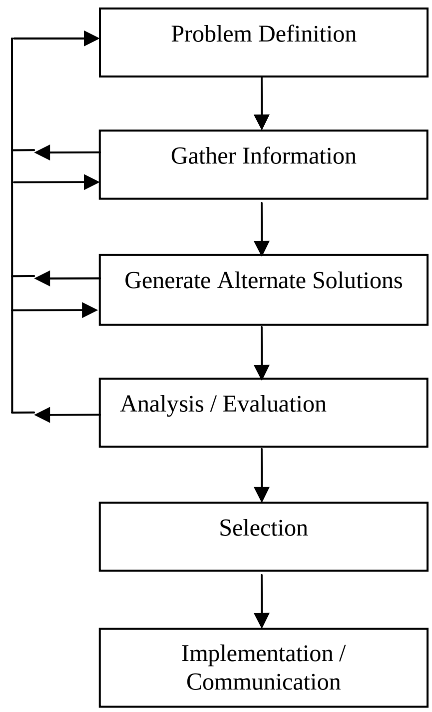
As a group, the engineers had breadth of experience in both the manufacturing and service sectors of the economy, and in firms marketing globally as well as nationally. Most reported having responsibility for the full span of design: conceptual design, detail design, and design implementation. Several also held leadership positions: 2 were president or partner of a firm, and 7 more reported their job title as lead engineer, senior engineer or manager. Participants had designed, among other things, transportation devices, amphitheatres, superconductors, turbines, waste disposal and recycling systems, nanoscale devices, integrated resource systems, HVAC systems, and payload configurations. Five held a professional engineer's license. Six participants had applied for a total of 19 patents, of which 3 participants had received a total of seven patents. Participants reported working on design teams with colleagues from diverse backgrounds including science and mathematics, business and management, and the arts and humanities (see Table 1 in Appendix A).

We used two criteria to identify and recruit practitioners who exemplified expertise in the domain of engineering design: 1) a social criterion—their identification as an expert in design by peers at work, and 2) the extent and type of their practical design experience (e.g., Ericcson and Simon[21] suggest at least 10 years of practical experience). We also chose practitioners who as a group would reflect a range of engineering subfields. This was to capture potential subfield differences, as well as to facilitate comparison with results from our earlier studies of undergraduate designers.[22,16] We purposely chose to include mechanical engineers as the bulk of the group. We advertised for volunteers through industry networks. Volunteers completed a screening survey asking about their education and employment background. Twenty-six individuals completed the screening survey, 20 of whom were selected for participation in the full study. The landscape architect was recruited as a point of contrast—someone with topic expertise in the chief design problem we asked participants to solve (designing a playground) but not expertise in the domain of engineering.

Task. Participants were asked to think aloud[23] as they read a 1-page description of the design process titled "One Model of the Engineering Design Process" (see Figure 3) based on the Atman and colleagues'[4] synthesis. We will refer to this description as the "one model." The "one model" task was administered during an individual 4-hour design session in which participants were asked to think aloud as they solved two engineering design problems (designing a playground and designing a flood containment device). Sessions were conducted at the participant's workplace or in our laboratory. The "one model" task was given after the playground task and before the flood task. In addition to being asked to think aloud as they read the "one model" description, participants were prompted to comment on it in relation to how they had just solved the playground problem.

We also present results from three other tasks administered during the last part of the design session. These were given in the form of a written questionnaire (see Appendix B). The first task, labeled "Your Illustration of Design," asked participants to: "Use this paper to create a picture or representation of what you think the process of design is." The second task (adapted from Newstetter and McCracken[14]), labeled "Your Ideas about Design," presented a list of terms and asked participants to choose the six most and least important. Specifically, it prompted, 1) "Of the twenty-three design activities below, put a check mark next to the six *most* important," 2) "Of the twenty-three design activities below [same list], put a check mark next to the six *least* important," and 3) "Are there any items that are missing from the list?" The final task, labeled "Your Definition of Design," asked participants to rate on a scale of 1 to 5 (strongly disagree to strongly agree) each of 27 statements about design. It then asked "Which statement do you agree with the most?" and "Which statement do you agree with the least?"

One Model of the Engineering Design Process



Problem Definition An important part of solving a problem is understanding exactly what the problem is. Your understanding must be accurate and complete. This involves knowing what goals your problem solution must meet and how you will evaluate whether your solution has met these goals. In addition, you must know if there are any constraints (or limitations) that you must be aware of. One example of a constraint is a limit on the amount of money that can be spent. Another example is whether the design must meet safety standards that the government has established. Once you have understood what the problem is you should then develop a plan for how to solve the problem.

Gathering information Now you need to identify and gather the information that is needed to solve the problem. The type of information you need depends on the kind of problem you are solving. Information can come from other people, technical sources such as books, or you can collect data for your specific problem. Sometimes you have to make assumptions if you can't find the exact piece of information you need. After information is gathered you often understand the problem better. This may mean that you end up modifying the definition of the problem.

Generation of alternative solutions After you have defined the problem and gathered the necessary information you should develop solutions to the problem. At this point you must be creative and think of as many ways to solve the problem as you can. Once again, while you are doing this you may find out that you need to gather more information or go back and modify the problem definition.

Analysis/Evaluation Now you need to figure out which of the possible solutions you have developed will actually work to solve the problem. At this point you use engineering analysis tools to determine whether each solution will meet or exceed the evaluation criteria that were established. Sometimes you actually have to build and test your design. Other times you can analyze your ideas with mathematical tools. You must also evaluate whether each solution meets other constraints of the problem such as safety and budget constraints. During this stage of the design process you may develop new ideas or change your original ideas to make them better. You may also find out that more information is necessary, or that the problem should be redefined.

Selection At this point you need to decide which one of your solutions is best. You should choose the solution that meets the design criteria and constraints developed when you defined the problem. Sometimes one of the solutions will do better to satisfy some criteria, while other solutions do better on different criteria. In this case you have to consider which criteria are the most important ones to meet, and then choose the design that meets them.

Implementation/Communication Once you have chosen the best alternative you must implement it. Implementation is the process of producing and installing a product or system and making it work. This often requires the cooperation of many people. That means that in order to have a successful implementation you must do a good job of communicating your ideas. This may involve convincing people that your design will solve their problem. To do a good job you may have to talk to a lot of people and you may have to produce a written report.

Figure 3. Elicitation task "One model of the Engineering Design Process."

Analyses

Analyses addressed the "one model" task and the three tasks in the questionnaire. To provide an overview of participants' beliefs and situate them broadly within the research landscape, we analyzed participants' responses to two of the questionnaire tasks (most and least important aspects of design, ratings of design statements). In addition, we qualitatively analyzed the results of the "one model" task and participants' sketches of the design process in tandem, to characterize participants' conceptions of design *in their own words*, in relation to the iconic block-flow model. A qualitative approach was essential here to capture potentially elusive qualities of individuals' design conceptions, with the goal of rich description. In the following paragraphs we provide details of this analysis.

Our analyses of the "one model" transcripts and sketches involved three phases. First, four of the authors and four undergraduate research assistants conducted a compare and contrast analysis[24] to identify themes in the data. Each analyst read the sketch and transcript of 3 study participants holistically, with the aim of creating a single list of themes evident in the participants' data. After first identifying themes in a single participant's data, the analyst then reviewed the second participants' data in comparison with this list, modifying the list of themes, and repeating the compare/contrast cycle for each remaining participant. All eight analysts' lists were then combined into one, producing 112 themes with supporting snippets of text as evidence for each of the themes. The lead author then pile sorted these into 13 thematic clusters. The senior research team prioritized three of these 13 thematic clusters as potentially richest to analyze first. In this paper we address one of those thematic clusters: the role of communication.

In the second pass through the transcript data, the lead author and a second undergraduate coder independently read through all the transcripts and identified episodes in the text relevant to the communication thematic cluster, defined as the role of communication (e.g., ways of communicating, purposes that communication serves, ways in which communication is important). The lead author identified 34 episodes and the second coder identified 23, a total of 35 separate episode units. We defined agreement between coders as the number of these 35 units which both coders had marked. We did not require exact congruence in episode start and stop point. Although intercoder agreement was moderate (simple agreement = 66%), the discrepancies showed this was almost entirely because the lead author was identifying more episodes as relevant to communication than the second coder. All discrepancies were resolved through discussion. In effect, we erred on the side of including episodes; only 2 of the 35 episodes initially identified by either of the two coders were dropped.

In the third pass through the transcript data, the lead author open coded each of the 33 communication episodes for the specific communicative role (i.e., communication competency) the episode addressed (e.g., to gather and broker stakeholders' ideas; to document and report the design). In the course of all three passes through the data, we identified one participant (Roger) we thought especially worth describing as a case, based on his view of communication as foundational to the engineering design process. In subsequent iterative readings of all communication episodes, we looked for both supporting and contrary evidence that Roger's view was shared.

We also conducted two pile sorts of the sketch data. The lead author and an undergraduate researcher conducted both pile sorts. In the first, sketches were sorted into 3 piles: in agreement with the "one model," in minor disagreement, and in major disagreement. We did so for each of two criteria: sequence of steps, and role or definition of actions in each step. Interrater agreement was low (simple agreement = 45%, adjusting for chance agreement, Cohen's Kappa = .20). On inspection, this was nearly all because of discrepancies over whether sketches were in agreement or minor disagreement with the one model (no participant replicated the "one model" exactly). Rather than attempt to further define the difference between agreement and minor disagreement, which seemed like splitting hairs, we chose to collapse the categories into two: 1) in agreement or minor disagreement with the "one model," and 2) in major disagreement. All 4 remaining discrepancies (judgments on both criteria for 2 participants) were resolved by the second author who served as tiebreaker. The lead author conducted a second pile sort resulting in five categories of sketches: vertical or horizontal block-flow diagrams, divergence/convergence diagrams, list of goals and questions, cyclical diagrams, and other. The undergraduate researcher independently sorted the sketches into these categories. Interrater agreement was 100%; Cohen's Kappa = 1. In the next section, we present the results of these initial analyses.

Results

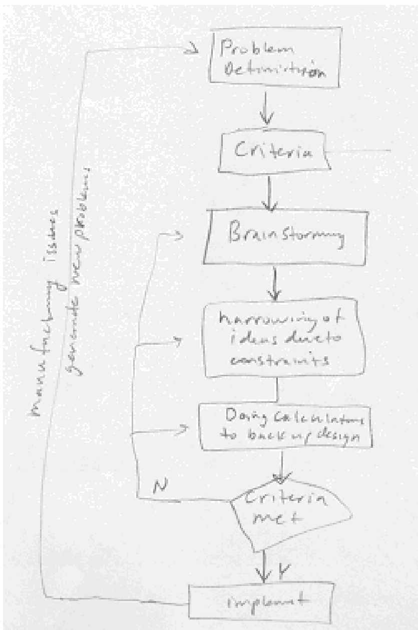
We present our results at three levels of description. First, we summarize results from our sorting of the design sketches to provide an overview of the participants as a group and how their sketches of the design process compared to the sequence and flow of the iconic block-flow model. To enhance this overview, we also report the engineers' choices of most and least important design activities and their ratings of statements describing design. Secondly, we look closely at the case of Roger, whose response to the "one model" so exemplified one of the most prominent themes in the data, that of communication. Third, we end by contextualizing Roger's remarks, presenting findings from the episodes on communication found across all 19 engineers' responses to the "one model."

How did the experts' sketches of the design process compare to the iconic block-flow model?

On the basis of their sketches and think-aloud responses to the iconic block-flow model, when these data were judged holistically and together, 16 of the 19 expert engineers were in agreement or minor disagreement with the "one model" we provided. The remaining 3 engineers were in major disagreement, all of whom drew a more cyclical diagram in which the final design activity was linked to the first. On the basis of our second pile sort into sketch types, as illustrated in Figure 4, among all 19 engineers, 11 drew vertical block-flow diagrams, 1 drew a horizontal block-flow diagram, 2 drew horizontal divergence/convergence diagrams, 1 made a list of broad goals and guiding questions (focused on problem definition), and 4 drew the type of cyclical diagrams characteristic of those 3 participants who most departed from the "one model."

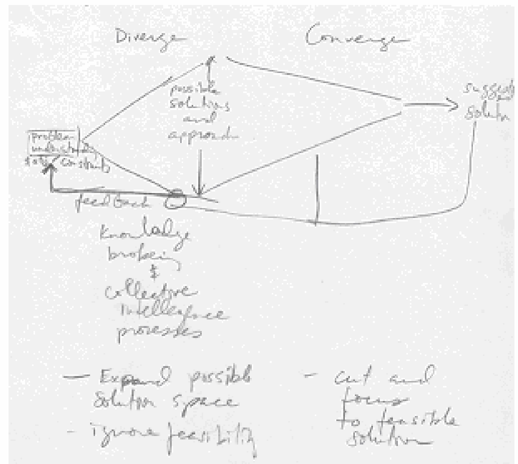
VERTICAL BLOCK FLOW (11)

Fred (CE), Peter (CE), Barbara (EE), Isaac (EE), Ann (IE), Nathan (ME), Eric (ME), Larry (ME), Mike (ME), Quincy (ME), Gary (MSE)



DIVERGENCE / CONVERGENCE (2)

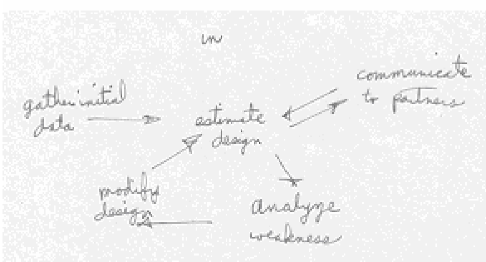
David (IE), Oscar (ME)



HORIZONTAL BLOCK FLOW (1) - John (SE) (NOT SHOWN)

CYCLICAL FLOW (4)

Allen (EE/PG), Kevin (ME), Roger (MSE), Bill (SE)



META GOALS / QUESTIONS (1)

Charles (ME)

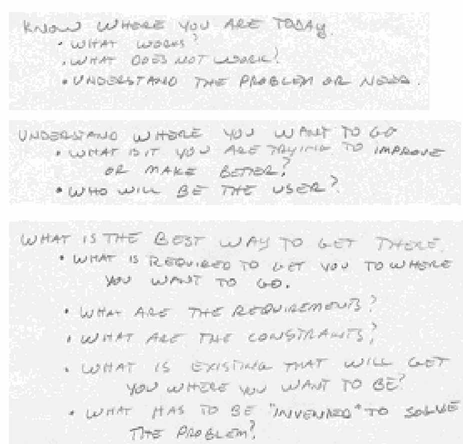


Figure 4. Experts' conceptions of the engineering design process as shown by the types of sketches they drew (with an example of each).

As shown in Figure 4, arrows and feedback loops were often included, in all of the diagram types (with the exception of the list of broad goals), signifying the sequence of the design process, or input from people such as users, or the need for iteration. No relation was found between the type of diagram drawn and the participants' subdiscipline of engineering. In stark contrast to the engineers, however, the landscape architect drew a light bulb.

Figure 5. A landscape architect's conception of design.

What terms and definitions did the experts choose as most and least descriptive of design?

As we described in the Methods section, each participant was also asked to complete two questionnaire tasks. The first task asked participants to select from a list of 23 terms the six most and the six least important design activities (see Appendix B). The list encompassed a broad range. It featured terms common to models of design processes (e.g., evaluating, brainstorming, understanding the problem), terms consistent with general design activities (e.g., sketching, synthesizing, communicating, iterating), and terms vaunted in philosophies of design (e.g., using creativity, making trade-offs, abstracting). As Figure 6 shows, the top terms, chosen by over half the 19 expert engineers, were "understanding the problem" (chosen by 15 individuals), "constraints" (chosen by 13), "communicating" (chosen by 12), and "seeking information" (chosen by 10). In other words, problem scoping and communicating activities were seen as the most important characterizations when asked to pick terms describing "your idea of design." In contrast, as Figure 6 also shows, the bottom terms, chosen by over half the engineers as "least important" were "decomposing" (chosen by 15), "abstracting" (chosen by 14), "building" (chosen by 13), and "synthesizing" (chosen by 10). Although some of these terms are abstract and may be unfamiliar, it is interesting to note that one common image of engineering, "building," ranked so low. Given the experts' choice of problem scoping and communication as chief descriptors, however, this is not so surprising.

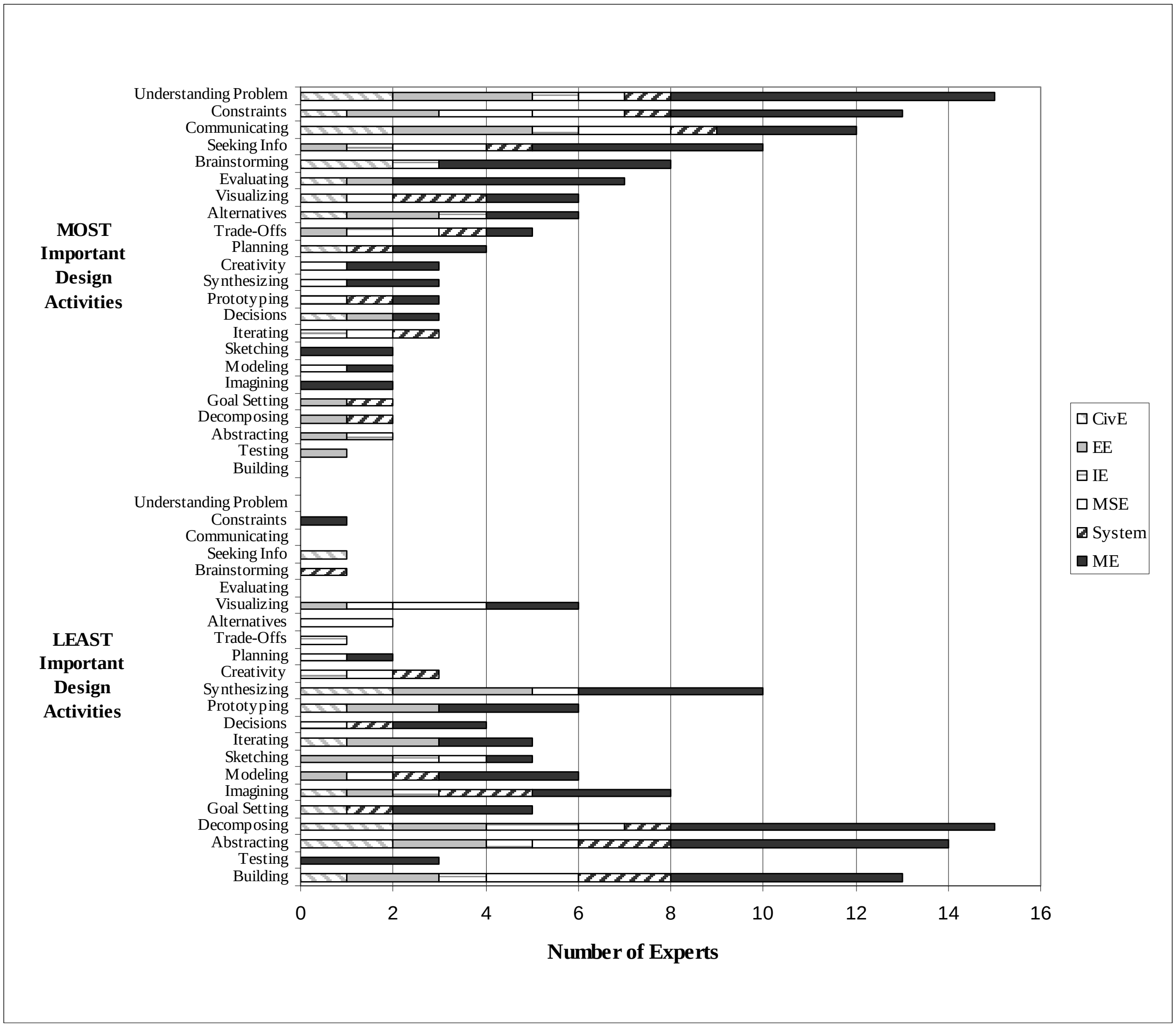


Figure 6. Participants' choice of the 6 most and the 6 least important of 23 design activities (aggregate count, n=19), by participants' engineering discipline. The landscape architect is not included.

In addition to asking participants to choose terms describing their "idea of design," we also asked them to rate 27 statements describing their "definition of design" on a scale of 1 (strongly disagree) to 5 (strongly agree). We also asked: Which statement do you agree with the most, and which do you agree with least? As shown in Table 2, the statement most strongly endorsed by the engineers was, "In design, a primary consideration . . . is 'Who will be using the product?'" The statement most weakly endorsed was, "Good designers get it right the first time."

Table 2. Endorsements of design statements (n=19, does not include landscape engineer)

Statement	Mean	StDev	Median	Mode
In design, a primary consideration throughout the process is addressing the question "Who will be using the product?"	4.5	0.6	5	5
Engineering design is the process of devising a system, component or process to meet a desired need.	4.4	0.6	4	4
Information is central to designing.	4.4	0.8	5	5
Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.	4.3	0.6	4	4
Design is not description of what is, it is the exploration of what might be.	4.2	0.5	4	4
In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.	4.2	0.8	4	5
Design is iteration.	4.2	0.8	4	4
Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.	4.1	0.7	4	4
Design is as much a matter of finding problems as it is of solving them.	4.0	1.0	4	5
Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.	4.0	0.6	4	4
Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.	3.9	0.7	4	4
Engineering design impacts every aspect of society.	3.9	1.1	4	5
In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.	3.8	0.9	4	4
Design in a major sense is the essence of engineering; Design, above all else, distinguishes engineering from science.	3.8	0.7	4	4
Design defines engineering. It's an engineer's job to create new things to improve society.	3.7	0.8	4	4
A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.	3.7	0.6	4	4
Good designers get it right the first time.	2.1	1.0	2	2

Consistent with participants' choice of the most important activities of design—evidence that they saw problem scoping and communication as at design's core—in the rating task they also favored descriptions indicative of a problem- and inquiry-focused conception. The particular statements participants most endorsed were diverse. Yet, overarching themes were consistent with that conception: design as user-focused; iterative and co-evolutional; a process of learning and exploration; and involving the use of visual representations to spur and communicate ideas. The results of these two descriptor tasks amplify views suggested in participants' sketches in Figure 4.

The case of Roger

In this section, we look more closely at Roger's conception of design. Not only did Roger's verbal response to the "one model" exemplify the theme of communication we had identified as prominent in our data, Roger was one of the 3 expert engineers whose sketch and verbal protocol, taken together, were in major disagreement with the "one model."

Roger was a material science engineer with over 20 years experience in the information technology industry and a Ph.D. in a subfield of material science engineering. He reported having served in his jobs as technical expert, lead engineer, project manager, and consultant. Past projects included designs for a metal-oxide varistor for a high-density, high-speed multichip module, and for a nanoscale memory device. Two of his design experiences had resulted in a patent.

Of the design definitions we presented, Roger agreed most with the statement, "Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers." He agreed least with the statement, "Good designers get it right the first time." Clearly, Roger rejected the light bulb view of design. He chose as the six most important design activities: seeking information, synthesizing, making tradeoffs, communicating, and iterating. He chose as the six least important: abstracting, generating alternatives, sketching, visualizing, building, and using creativity.

In response to the last block of the "one model" labeled "Implementation / Communication," Roger said:

> [T]here's this idea that engineers are focused on things, they're not people-people. Well, in a modern corporation, if you want to get something done, you do it with people. . . . You don't go away in the lab and work on something for a year and then burst forth with the glory and a halo around your head and look at what cool thing I've created. . . . First off, where did you get the funding to do that? Where did you get the equipment? Where did you get the support staff? If you're doing things like we do here . . . we're talking about tens of millions of dollars worth of equipment. Well, you're not gonna just sort of sneak this in for a couple years until you've got the perfect product. You've got to work with people.

Communication, said Roger, was being given "short shift," both here in the block model and in many companies, "and it's a reason for many failures." The engineer's ability to communicate and negotiate, in his view, was foundational to engineering projects, not merely the last phase in delivering on a design. It set parameters, real resources at the engineer's disposal—the funding, the equipment, the support staff. Ignoring these "process world" realities, to use Buciarelli's[3,18] term, was inviting failure.

That Roger offered such a hard-nosed reality check on engineering as *thing* focused reflects another aspect of his view of the engineer's communicative role in the design process. "You can't satisfy all the people all the time," he said, and that is one difference between engineers and scientists:

> Engineers look for the possible. They look for what is economically rational—what will meet the market requirements in the time allowed, with the money available to develop it, and the cost goals. And they also sometimes tell other people, upper management, marketing, sales, production: 'You're crazy, you can't do it, it doesn't work. It is not physically possible. It is physically possible, but with these limitations that we have in place, it's not gonna happen.'

The engineer worth his or her salt, in other words, is sometimes the bearer of harsh news; the engineer's role is to be the voice of economic reason. That means translating physical possibilities and limits into understandable language for people from other areas of expertise—not just as a scientist might, but always in light of production time and costs. According to Roger, this meant communicating possibilities and implications throughout the entire design process.

> [T]he communication part has to start way back in problem definition, and it has to then proceed and be considered at each point along the solution definition path. That's especially true in something like the exercise we did today, where you want something for the community. Well, it's almost guaranteeing you to fail if you were to say, well, I think this is the way it should be, and we're going to build it this way. I can assure you that the community would be unhappy, because there will be people who will say, well, we need more benches or we don't want seesaws because my kid chipped a tooth on a seesaw at another playground or . . .

Waiting to communicate one's design intent and instructions until after they are worked out was, in Roger's view, poor design strategy—but not necessarily in all cases:

> [T]his sort of linear approach to design is fine for a small project. For a large project, which includes multiple people, whether it's multiple members of the community, or it's manufacturing, finance, engineering, planning, personnel, upper management, and you've got to get everybody synchronized and everybody pulling in the same direction, then it just doesn't work.

Indeed, one of the most interesting things about Roger's view was his belief that communication demands were a major criterion distinguishing small simple projects from large complex ones, and thus distinguishing junior from senior engineers.

> [T]he [junior] engineer will do his or her project just fine, but what most companies demand of their senior engineers — well, they actually split it up, there's two flavors of senior engineers. One flavor is a person who is an acknowledged expert in an area. And if you want to know the property or you want a reasonable estimate of what's going to happen if I do this, they're the person to go to. But most of the senior engineering staff are people who can get things done within the organization, and that means the communication, the contacts, the awareness of multiple viewpoints, the ability to generate consensus, negotiating, getting to yes; it's understanding the needs of each viewpoint and what that person considers nonnegotiable and what they consider as . . . . musts, strong wants, and wants. And so the concept is how are you going to meet everyone's musts, or at least meet as many of the musts as you can, and at the same time, try to hit as many of the strong wants? And it's a juggling act, it's a balancing act.

In his description of the two "flavors" of senior engineers, Roger suggests two kinds of communication know-how that separate novices from expert engineers. The first is the ability to respond to the inquiries of others, who may not be engineers, with reasonable estimates of how someone's general design idea is going to work physically, and at what time and cost to produce. This means drawing on knowledge of past solutions and solution principles, then translating conclusions relatively swiftly for the inquirer, in terms the inquirer can understand. The second is the ability to negotiate multiple—and often multidisciplinary—viewpoints. The language that Roger uses to describe this identifying and balancing of viewpoints—musts, strong wants, and wants—is characteristic of negotiation philosophy in general (cf. Fisher & Ury[25]). But it has special significance for the engineer: Musts, strong wants, and wants help define the engineering problem, becoming criteria and constraints for the solution to be engineered. The skill with which stakeholders' needs and wants are negotiated thus sets the stage in problem definition (the first block in "one model"), but those needs and wants are not set in stone. They remain subject to change and renegotiation throughout the design process. The senior engineer must navigate and lead the design process in light of their contingency.

In short, expert engineers, in Roger's view, are valued for specific communicative abilities they possess. The first is estimating fluently for others. The second is negotiating musts, strong wants, and wants with others. Neither flavor of senior engineer staves off communication until the last phase in the design process, when the object designed is ready to be heralded, sold, and built. Nor do they simply keep others apprised of what they are doing. In fact, a third communicative ability that Roger held up as key was actively seeking multiple viewpoints from others, as part of the design process.

> At least in my world, you don't define a problem, come up with a solution, and then publish it out and say this is what we're going to do. Instead, you come up with a potential solution, and you say to people, what do you think of this? Have you got any ideas? Does this work for you? Does this meet your problem statement, which may be significantly different than mine? It may be that they see something from a different viewpoint. It may be from a financial viewpoint or from a liability viewpoint or from an ability to do it smoothly and consistently in a manufacturing environment. All of those are maybe different viewpoints than strictly an engineering viewpoint. Sort of like the story of the elephant and the blind men . . . [O]ne grabs the trunk and says, oh, an elephant is like a snake. . . . And the fifth one grabs the tail and says, oh, an elephant is like a rope. Well, I mean it's – they're all correct. It depends on what hunk of the elephant you grabbed. And it's the same sort of thing: In order to have successful implementation of a complex project, you can't look at it from one viewpoint. You have to have multiple viewpoints.

In Roger's view, the successful engineer is one who seeks feedback on his or her plans in a way that leverages multiple viewpoints—and does so relatively early in the design process.

As Ferguson[17] notes, engineers have never been mere tinkerers with things. They have always had to enlist the support of patrons for their ideas. "When President John Kennedy called for the United States to put a man on the moon," he writes, "engineers at NASA had [already] proposed such an expedition as the ninth step in a comprehensive space program. The crucial problem for the engineers was not to determine how to get to the moon but rather to find a patron who would furnish the money and give the program political legitimacy." Roger's conception of the design process spotlights communication. But communication here is not limited to selling one's design ideas (whether to secure initial funding or a final buy-off) or to detailing the design for builders. The communicative competencies tapped are therefore not limited to persuasion and documentation. They are intimately tied up with a conception of design as a collaborative process in which a lot of people have their say. In Roger's comments, this collaboration is presented less as an ideal to be aimed for than as a simple fact of modern corporate life. Making the most of a culture in which clients of all stripes increasingly expect to have their voices heard and no longer look to "experts" as the sole authority in any domain calls on a particular vein of expertise: the engineer's abilities to translate for and orchestrate with others possibilities, criteria and constraints at every step of the design process.

The fact that Roger classifies design projects into two types (small/simple and large/complex) and thinks that the block-flow diagram is applicable to small/simple projects but not to large/complex ones may be one feature of expert design thinking and knowing. Similarly, Roger's recognition of two "flavors" of expert engineers (one good at estimating fluently for others, and the other good at negotiating needs and wants with others) may signal another attribute of engineering expertise. In other words, sensitivity to communicative opportunities and demands in the particular work context may be one hallmark of the expert who does not see an engineering design problem as given but rather reframes the problem to create an innovative and generative solution—what Bransford[26] and others refer to as the difference between routine and adaptive expertise.

Interestingly, when commenting on the "one model" and how it related to what he had just done in the playground problem, Roger said he did *not* generally try to generate alternative solutions as the "one model" recommends.

> It's very rare that I'll do two or three or more solutions, alternative solutions to a problem, work them through, and then compare them, and say, well, this has those points and that has those points, and so this one is better and that one is worse. There's rarely time to do that, and there's — it's not clear to me that the cost-benefit exists. There's a — in engineering, especially in development engineering, there's strong time constraints and there's very significant cost and resource constraints. So to generate multiple solutions is, in my experience, rarely possible.

Roger did not claim that generating alternative solutions was irrelevant to innovation. In some ways, he said, his approach was an example of "the good being the enemy of the great, or of the perfect or excellent." In place of the "one model" approach to achieving excellence that we presented, the model Roger subscribed to for achieving excellence was that of "continuous improvement." "What I generally do," he said, "is try a solution, figure out what's wrong with it, and then go back and modify the solution." He said, "You end up getting something that's good enough to meet your criteria initially—sometimes it isn't even good enough, sometimes just close—and then from there you work to optimize that, to improve it." He said:

> Rather than this model of generate alternative solutions and analyze and evaluate and then select, what I tend to do, or I tend to believe, and I think most people do, is closer to a virtual cycle of so-called implement, evaluate, modify, and then you

> implement again, and you evaluate again, and you modify again, so the so-called continuous improvement. . . . [U]sing Post-Its means that you can do an iterative process. You don't have to be perfect the first time around. And eventually you get to the point where it's good enough.

It is easy to imagine an engineer sequestered in his or her cubicle pushing Post-Its around failing to hit on an innovative or generative solution. Roger's strategy makes sense, perhaps, only when wedded to the kind of open, multi-participant, and multidisciplinary process he proclaims is a fact and asset of engineering design in today's corporate life. That Roger jumps to an initial solution before generating any alternatives may also seem to also be a recipe for "design fixation" (i.e., stubbornly sticking to a solution without exploring alternatives, regardless of flaws that crop up), a trait some experienced designers have been found to exhibit.[15,19] But his remarks and sketch suggest another way to read this behavior. The center point of Roger's sketch is "estimate design," a tentative solution thought to be a good start based on his knowledge in the domain, which in turn serves as a work-in-progress around which to get the attention of others, and engage multiple perspectives in a continuous improvement cycle. What might a graphic of the continuous improvement model look like?

The sketch Roger produced when asked to draw his representation of the engineering design process is shown in Figure 4. Although the flow through this figure, as in other block-flow diagrams, can be traced sequentially, it reflects Roger's very first comment when reading the description of the "one model": "I find the design process to be significantly nonlinear." Roger's was one among only 4 cyclical diagrams that the 19 engineers in this study drew. His sketch shows "communicate with partners" as one way-station in the design sequence. But because the design sequence is conceptualized as cycle of continuous improvement, that way station, the sketch implies, is a checkpoint visited again and again.

How did Roger compare to the rest of the group's views of communication?

To what extent was Roger's view of communication in the engineering design process echoed by the other engineers in this study? What did they stress as engineers' most important communicative competencies? Of the 33 episodes addressing communication we identified in the transcripts, 30 were comments by engineers other than Roger, and none were by the landscape architect. Counting Roger, comments about the role of communication were made by 17 of the 19 engineers. Table 3 shows the topic of these comments by the number of engineers and pseudonyms of the engineers who spoke of each.

It is not surprising that the two most frequently mentioned topics were detailing the design for builders, and documenting and reporting the design. After all, that is what the "one model" paragraph on Implementation/Communication described. In their comments, most of these experts affirmed the importance of detailing and reporting well, saying that had they more time in the exercise, they would have kept honing their drawings, instructions, and reports to a finer degree of specification and clarity. What is potentially notable about this for expertise is that it suggests experts may be readily able to gauge what is a necessary and sufficient level of documentation at various stages of a design process and adjust their documenting activities accordingly, even though they hold the general principle that more detail is better.

Table 3. Topic of communication comments (episodes) by engineer

TOPIC	NUMBER OF ENGINEERS MENTIONING THE TOPIC	SPECIFIC ENGINEERS MENTIONING THE TOPIC
COMMUNICATE TO:		
▪ Detail the design for builders	10	Bill, Barbara, Charles, Eric, Fred, Gary, Kevin, Oscar, Peter, Quincy
▪ Document and report the design (e.g., to persuade others to accept it).	7	Barbara, David, Fred, Isaac, Larry, Nathan, Quincy
▪ Secure group agreement on design ideas	4 (including **Roger**)	Bill, David, John, **Roger**
▪ Gather and broker stakeholders' ideas	2 (including **Roger**)	David, **Roger**
▪ Draw on others' technical expertise during problem definition and analysis	2	Isaac, John
▪ Draw on users' experience during problem definition and information gathering	1	Oscar
▪ Lead non-engineers when design is by group process	1	John
▪ Manage customer's changing criteria	1	John
▪ Check for designer's own error or bias	1	David
▪ Verify designer's assumptions	1	Nathan
▪ Convey estimates of the technical and economic implications of design ideas	1 (**Roger**)	**Roger**
▪ Keep in touch with supervisors (who are likely no longer in earshot as was true in the past)	1	Fred
▪ Convey design intent to non-engineers (e.g., CAD designers; the public, city officials, and other stakeholders)	1	Fred
▪ Ensure institutional memory when design is by group process	1	Ann

Because of the way we solicited the experts' conception of communication in the design process, we cannot definitively say how much these experts would agree with Roger's conception of the centrality of communication in design. Several of their spontaneous comments, however, also concerned exploiting the fact and asset of design as a social process. Most frequently, this was in terms of securing group agreement on design ideas or gathering and brokering stakeholders' ideas. Said David and Bill:

> [O]ne of the weaknesses I think in this [task] construction is using myself as the primary resource base for ideas. I think it's important to always maximize the brains that are contributing ideas. . . . I'm feeling that you need to broker ideas with as many places as possible, people, parents, talk to the constituencies. . . . I think that selection is best done using collective intelligence. (David)

> If I was doing this for real, I wouldn't do it all by myself. As I said earlier, I would come up with some sketches, you know, like this, and go shop those around and get some agreement on various things like that, and then work on individual pieces, rather than say, this is what we're thinking about doing on this piece, and that sort of thing. So maybe it's an artifact of doing studies versus doing real-world stuff. (Bill)

Other communication topics the experts mentioned also suggested a conception of design as an open, multi-participant, or multidisciplinary process, in which the designer him- or herself is just one source of design expertise. Among the topics shown in Table 2, six topics (in addition to securing group agreement on design ideas or gathering and brokering stakeholders' ideas) especially illustrate this point: drawing on others' technical expertise during problem definition and analysis, leading non-engineers when design is by group process, managing customer's changing criteria, checking for designer's own error or bias, verifying the designer's own assumptions, and ensuring institutional memory when design is by group process. Stressing the need to communicate to manage a customer's changing critieria, for example, John pointed out how ignoring the contingent nature of a customer's criteria (and the engineer's need to manage this contingency) could spell failure.

> [M]ost of the things I deal with are usually very complex and engage teams a lot. . . . I want to stay engaged with a customer during the problem definition phase, the information gathering phase, and so on, and just make sure they're not going to give me some surprises or – you know, the ultimate concern in any of this people don't know what to tell you until you do things that trigger them to remember, and so by engaging them, you minimize surprises later on, which is usually the biggest cost concern in any project, is you may get all the way down the road, and then you find out, oh, geez, nobody wanted, you know, natural wood, they wanted it painted, or something. (John)

The breadth of these experts' communication topics and examples, offered within this small clinical task, suggest that expert engineer-designers value a range of identifiable communicative competencies at play throughout the design process.

Conclusion

Most of the engineers in this study did not directly challenge the block-flow model of the engineering design process. They assimilated their conceptions of the design process to it. Further, drawing a linear block-flow model themselves when asked to sketch their own representation of the engineering design process did not appear related to the experts' subfield of engineering. (Although the participants' sketches and comments may have been influenced by the "one model" description we presented, such exposure is unlikely to have persuaded experienced practitioners away from their own ideas.) This evidence suggests that the block-flow model is not something most expert engineers cast off or find irrelevant to their activities; they recognize it and continue to exercise it as a shared conception in some fashion.

Seven of the 19 engineers, however, did draw alternate kinds of representations of the engineering design process. Notably, 4 of these engineers (again, from various subfields of engineering) drew less linear, more cyclical diagrams, similar to the trend in recent introductory engineering textbooks emphasizing not only iteration but teamwork and concurrent engineering.

Even among the engineers in our study who did not draw cyclical diagrams, the theme of communication was among the most prominent in their remarks. A broad range of specific communicative competencies were valued. Taken together, many of these suggest a view of engineering design process as open, multi-participant, and multidisciplinary, in which the engineer-designer is not the sole source of design expertise. With teaming in parts or all of the design process, proactive communication is seen as necessary, in part, to manage design ideas and decisions that are increasingly seen as brokered contingencies. Among the engineer's communicative competencies highlighted were drawing on others' technical expertise during problem definition and analysis, leading non-engineers when design is by group process, managing customer's changing criteria, checking for designer's own error or bias, verifying the designer's own assumptions, and ensuring institutional memory when design is by group process.

The case of Roger, who rejected the block-flow diagram we presented, and portrayed communication as fundamental to the engineering design enterprise, illustrates a conception of engineering design that acknowledges the limits of the block-flow model to account for how experts exploit communicative opportunities and demands in large, complex engineering design projects. In particular, he highlighted two specific communicative competencies as markers of the expert engineer valued in today's corporate world: 1) estimating fluently for others, and 2) negotiating musts, strong wants, and wants with others. In addition, he held up 3) actively seeking multiple viewpoints from others, as part of the design process. Conceptualizing the engineering design process as that of "continuous improvement" rather than a linear block-flow diagram, Roger's model did not confine communicating with partners to any particular stage of the design process.

Roger's belief that the block-flow diagram is applicable to small/simple projects but not to large/complex ones may be one feature of expert design thinking and knowing. Similarly, Roger's recognition that there are two "flavors" of expert engineers (one good at estimating fluently for others, and the other good at negotiating needs and wants with others) may signal important knowledge about variants in design expertise. Attending to communicative opportunities and demands in the particular work context with these lenses may be one hallmark of adaptive expertise.

Our results are further support for the argument that conceptualizing engineering design expertise as following the boxes and arrows of the block-flow model may underestimate the competencies, and in particular the communicative competencies, that characterize expertise in engineering design. Although it is possible to read the iconic block-flow model (and our "one model" presentation of it) as not precluding communication at each stage of the design process (and, indeed, this may help explain why our experts assimilated their conceptions to it), the model is hauntingly silent on concurrency and the demands that others may make to be involved in the design process.

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Authors
SUSAN MOSBORG is a Research Scientist at the Center for Engineering Learning and Teaching (CELT) in the College of Engineering at the University of Washington. She received her doctoral degree in educational psychology at the University of Washington. Dr. Mosborg's research interests include how people learn about the past and about current public affairs, and the relation between learning in informal and formal settings.

ROBIN ADAMS is the Assistant Director for Research at the Center for Engineering Learning and Teaching (CELT) in the College of Engineering at the University of Washington and starting in Summer 2005 will be an Assistant Professor in Engineering Education at Purdue University. She is also the lead for the Institute for Scholarship on Engineering Education (ISEE) as part of the Center for the Advancement of Engineering Education (CAEE). Dr. Adams's research concentrates on design learning and conceptions of design, strategies for promoting leadership in engineering education, and understanding interdisciplinary capacity (the ability to work at the interfaces between disciplines).

REBECCA KIM is an Undergraduate Research Assistant at the Center for Engineering Learning and Teaching (CELT). She is a second-year Biochemistry and Environmental Studies student in the University of Washington Honors program. Rebecca's professional goal is to conduct biomedical research, particularly in the area of retinal diseases.

CYNTHIA ATMAN is the founding Director of the Center for Engineering Learning and Teaching (CELT) in the College of Engineering at the University of Washington and the director of the NSF funded Center for the Advancement of Engineering Education (CAEE). Dr. Atman is a Professor in Industrial Engineering. Her research focuses on design learning and engineering education.

JENNIFER TURNS is an Assistant Professor in Technical Communication in the College of Engineering at the University of Washington. Dr. Turns' research concentrates on user-centered design, the use of portfolios to support engineering students' conceptions of professional practice, and understanding teaching challenges in engineering education.

MONICA CARDELLA is a Doctoral Candidate in Industrial Engineering at the University of Washington and a Graduate Research Associate at the Center for Engineering Learning and Teaching (CELT). Monica's research interests include engineering education, engineering design, mathematical
thinking, and sketching.

Appendix A: Table 1

Table 1. Number of experts who said they had worked with design team members from various fields, by team member's field.

ENGINEERING		MATH SCIENCE		BUSINESS		ART HUMANITIES		OTHER DESIGN		OTHER	
Aero/Astro	4	Applied Math	3	Accounting	8	Anthro	1	Arch	4	Const Mgmt	4
Biomedical	2	Atmos Sci	1	Admin	5	Artist	2	CAD	13	Electrician	5
Ceramic	1	Biochemistry	1	Business	5	Education	2	Graphic	4	Real Estate	4
Chemical	5	Biology	3	Economic	2	History	1	Industrial	8		
Civil	9	Chemistry	4	Finance	3	Linguistics	0	Land Arch	4		
Cognitive	2	Geology	2	H Resources	2	Music	1	Museum	1		
Computer	5	Info Sys	7	Marketing	6	Psych	2	Urban Plan	2		
Comp Prog	7	Medicine	3	Proj Mgmt	7	Pub Policy	3				
Electrical	14	Physics	6	Training	4	Sociology	2				
Environmental	5	Statistics	5			Theatre	1				
Forestry	1										
Hardware	5										
Human Factors	8										
Industrial	7										
Manufacturing	7										
Materials Sci	8										
Mechanical	12										
Nuclear	0										
Operations	5										
Quality	7										
Software	8										
Structural	8										
Tech Comm	4										
Transportation	4										

Appendix B: Questionnaire

Part 1: Your Illustration of Design

Use this paper to create a picture or representation of what you think the process of design is.

Part 2: Your Ideas about Design

Of the twenty-three design activities below, put a check mark next to the six *most* important

a. Abstracting	m. Making trade-offs
b. Brainstorming	n. Modeling
c. Building	o. Planning
d. Communicating	p. Prototyping
e. Decomposing	q. Seeking Information
f. Evaluating	r. Sketching
g. Generating alternatives	s. Synthesizing
h. Goal Setting	t. Testing
i. Identifying Constraints	u. Understanding the problem
j. Imagining	v. Using creativity
k. Iterating	w. Visualizing
l. Making decisions	

Of the twenty-three design activities below, put a check mark next to the six *least* important.

a. Abstracting	m. Making trade-offs
b. Brainstorming	n. Modeling
c. Building	o. Planning
d. Communicating	p. Prototyping
e. Decomposing	q. Seeking Information
f. Evaluating	r. Sketching
g. Generating alternatives	s. Synthesizing
h. Goal Setting	t. Testing
i. Identifying Constraints	u. Understanding the problem
j. Imagining	v. Using creativity
k. Iterating	w. Visualizing
l. Making decisions	

Are there any terms that are missing from the lists?

Part 3: Your Definition of Design

1. Below are a number of statements people have made about design. We expect that different statements will appeal to different people. In the table below, please indicate the extent to which you agree with the statement provided (i.e., speaks to you, resonates with you, you agree with it, etc.). **Circle 1 if you strongly disagree, 2 if you disagree, 3 if you neither agree nor disagree, 4 if you agree or 5 if you strongly agree.**

I believe:	**Strongly Disagree**	**Disagree**	**Neither agree nor disagree**	**Agree**	**Strongly Agree**
1. Good designers get it right the first time.	1	2	3	4	5
2. Good designers have intrinsic design ability.	1	2	3	4	5
3. In design, a primary consideration throughout the process is addressing the question "Who will be using the product?"	1	2	3	4	5
4. Visual representations are primarily used to communicate the final design to a teammate or the client.	1	2	3	4	5
5. Engineering design is the process of devising a system, component or process to meet a desired need.	1	2	3	4	5
6. Design in a major sense is the essence of engineering; Design, above all else, distinguishes engineering from science.	1	2	3	4	5
7. Design begins with the identification of a need and ends with a product or system in the hands of a user.	1	2	3	4	5
8. Design is primarily concerned with synthesis rather than the analysis, which is central to engineering science.	1	2	3	4	5
9. …design is a communicative act directed towards the planning and shaping of human experience. The task of the designer is to conceive, plan, and construct artifacts that are appropriate to human situations, drawing knowledge and ideas from all the arts and sciences.	1	2	3	4	5
10. Design is as much a matter of finding problems as it is of solving them.	1	2	3	4	5
11. In design it is often not possible to say which bit of the problem is solved by which bit of the solution. One element of a design is likely to solve simultaneously more than one part of the problem.	1	2	3	4	5
12. Design is a highly complex and sophisticated skill. It is not a mystical ability given only to those with deep, profound powers.	1	2	3	4	5
13. Designing as a conversation with the materials of a situation.	1	2	3	4	5
14. Design defines engineering. It's an engineer's job to create new things to improve society.	1	2	3	4	5
15. Design is not description of what is, it is the exploration of what might be.	1	2	3	4	5
16. Design is often solution-led, in that early on the designer proposes solutions in order to better understand the problem.	1	2	3	4	5
17. In design, the problem and the solution co-evolve, where an advance in the solution leads to a new understanding of the problem, and a new understanding of the problem leads to a 'surprise' that drives the originality streak in a design project.	1	2	3	4	5
18. Design is a goal-oriented, constrained, decision-making activity.	1	2	3	4	5
19. Designers operate within a context which depends on the designer's perception of the context	1	2	3	4	5
20. Creativity is integral to design, and in every design project creativity can be found.	1	2	3	4	5
21. Engineering design impacts every aspect of society.	1	2	3	4	5
22. A critical consideration for design is developing products, services, and systems that take account of eco-design principles such as use of green materials, design for dismantling, and increased energy efficiency.	1	2	3	4	5
23. Design is "world" creation; everyone engages in design all the time. It is the oldest form of human inquiry giving rise to everything from cosmologies to tools.	1	2	3	4	5
24. Design, in itself, is a learning activity where a designer continuously refines and expands their knowledge of design.	1	2	3	4	5

25. Designers use visual representations as a means of reasoning that gives rise to ideas and helps bring about the creation of form in design.	1	2	3	4	5
26. Information is central to designing.	1	2	3	4	5
27. Design is iteration.	1	2	3	4	5

2. Which statement do you agree with the most?
3. Which statement do you agree with the least?