Softening Up the Facts: Engineers in Design Meetings

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1 Engineering Design in Theory and Practice

Engineering design is, perhaps, the most consistently complex of design processes—both in terms of the technical problem solving involved and the huge numbers of people having to communicate with each other in the average project. In a recent book describing the design and development of the Ford Taurus, for example, the author estimates 300 people were involved in producing a product with 30,000 parts.[1] It is self-evident, then, that engineering problems require both technical and social expertise. However, perceptions of engineering designers generally tend to simplify their character and role within a social and societal context. Although they often have a fine understanding of technical issues (allied with an uncanny ability to use computers effectively) this reasoning goes, they lack the social skills necessary for "good" communication, and tend to be reactionary or simply dull.

There is, however, a growing body of work recapturing something of the "humanity of engineering design," often by concentrating on the epistemology of practice,[2] but also by studying and documenting the highly specialized ways in which social interaction mediates technical problem-solving processes.[3] By refocusing on these aspects of engineering design *as it is experienced,* an identifiable constructivist approach has begun to emerge (drawing from, for example, the work of Donald Schön and Nelson Goodman[4]). This approach has arisen in opposition to rather Taylorist notions of "engineering design science,"[5] which holds that good engineering design is a result of following a normative set of scientifically determined procedures. Schön terms these notions pejoratively as "technical rationality."[6] They usually are voiced by stressing a way of working over the qualities of the people carrying out the work. The following quote provides an impression of a process "waiting to happen":

> By identifying and quantifying factors that affect critical element positions early in the configuration design stage, a design team is in a better position to specify a configuration that accommodates all the critical relationships necessary for function in a machine.[7]

1 M. Walton, *Car: A Drama of the American Workplace* (New York: W.W. Norton & Company, 1997).

2 S. Florman, *The Existential Pleasures of Engineering Design* (2nd Edition) (New York: St. Martin's Press, 1996), E.S. Ferguson, *Engineering and the Minds Eye* (Cambridge, MA: MIT Press, 1993); J.E. Holt, "The Designer's Judgment," *Design Studies* 18 (1997): 113-123; D.A. Schön, "Designing: Rules, Types, and Worlds," Design Studies 9 (1988): 181-190; W.G. Vincenti, *What Engineers Know and How They Know It: Analytical Studies From Aeronautical History* (Baltimore: John Hopkins University Press, 1990).

3 L.L. Bucciarelli, "An Ethnographic Perspective on Engineering Design," *Design Studies* 9 (1988): 159-168; L.L. Bucciarelli, *Designing Engineers* (Cambridge, MA: MIT Press, 1994); K. Grint and S. Woolgar,*The Machine at Work: Technology, Work, and Organization* (Cambridge, UK: Polity Press, 1997); T. Kidder, *The Soul of a New Machine* (Harmonsworth, UK: Penguin, 1981); S.L. Minneman, *The Social Construction of a Technical Reality: Empirical Studies of Group Engineering Design Practice* (Ph.D. thesis, Stanford University, 1991); and ⁰M. Walton, *Car: A Drama of the American Workplace.*

4 D.A. Schön, *The Reflective Practitioner* (London: Temple Smith, 1983); and N. Goodman, "Words, Works, Worlds" in *Ways of World Making,* N. Goodman, (Indianapolis: Hackett Publishing Co., 1978), 17-29.

5 V. Hubka and W. Ernst Eder, "A Scientific Approach to Engineering Design," *Design Studies* 8 (1987): 123-137; and G. Pahland and W. Beitz, *Engineering Design* (London: The Design Council, 1984),6.

The unnamed "design team" has only to execute this process correctly. There is a clear indication that the correctness of this method applies independently of the people who find themselves in this design process, and who are then bound either to be passive or to be wrong.[8]

This kind of "scientific" view contrasts very strongly with anyone familiar with the average engineering design meeting. The participants usually are anything but passive, often using a variety of means to get their point of view across. It is in these design meetings that one begins to observe very particular things: the past experiences, intuitions, and preferences of participants; the present subject in relation to the organizational history; the varying relationships between those present; the misunderstandings that occur; and even the surprisingly questionable and ephemeral nature of technical information. Most of all, one notices how these contingencies are expressed, interpreted, and re-expressed through language. One notices how words and phrases can refer to actual things, but also how they construct design opportunities and possible futures. In a previous paper,[9] the mechanism of "storytelling" was described in which individual narratives—often collapsed into a word or phrase—act as touchstones in social exchanges. The point here is that, in a very real sense, designers—engineering or otherwise—spend a great deal of time talking about something that, although slowly coming into existence, doesn't exist.

In a series of conversational vignettes, this paper will attempt to show just how far the process of engineering design is a process dependent on sketching out possible futures in words. It will conclude by suggesting that, if this "verbal sketching" ability indeed is a large part of being an experienced engineering designer, then, perhaps, courses promoting this skill, for example in rhetoric, should be explicitly taught at undergraduate level.

2 The Study of Language in the Design Process

Studies of the design process through an analysis of language are becoming increasingly popular.[10] They often center around the idea that every design situation is unique, and that, in design conversations a kind of "world" is constructed with its own references, assumptions, symbol systems, and contributing experiences. With a close reading of these conversations, it has been possible to examine the construction of such a "world" and to identify mechanisms by which language functions in relation to a developing artifact. Elsewhere, cognitive studies have mentioned the idea of a particular "designerly" way of thinking,[11] and studies that focus on language seem to be asking a similar question: "Is there a designerly way of talking?"

David Fleming,[12] examining student/supervisor discussions in a graphic design project, finds a difference between what he terms "object-laden talk" and "language-laden talk." The former

6 D.A. Schön, *The Reflective Practitioner*, 21-69.

7 K. Harrison and C.C. Wilson, "Evaluating Configuration Complexity in Machines," *Journal of Engineering Design* 8 (1997): 165-174.

8 Larry Bucciarelli in *Design Engineers* describes a similar episode (152-159). At the beginning of a design meeting, a "performance specification" is set and those present try to choose between alternative design solutions as the method prescribes. However, no one can agree on just what constitutes a "performance specification." Bucciarelli comments that, although those present at the meeting felt it was a disaster, the conversation that occurred actually was useful. It helped to develop "shared meanings" and begin to construct the discursive "objects of design."

9 P. Lloyd, "Storytelling and the Development of Discourse in the Engineering Design Process," *Design Studies* (2000): 367-73.

10 L.L. Bucciarelli, *Design Engineers*, and D. Fleming, "Design Talk: Constructing the Object in Studio Conversations," *Design Issues* 14 (1998): 41-62; P. Lloyd, "Storytelling and the Development of Discourse in the Engineering Design Process"; and P. Medway, "Building With Words: Discourse in an Architect's Office" in *Carleton Papers in Applied Language Studies* (Vol. IX) (Ottawa: Carleton University, 1992), 1-32.

11 N. Cross, "Discovering Design Ability" in *Discovering Design: Explorations in Design Studies* R. Buchanan and V. Margolin, eds. (Chicago: University of Chicago Press, 1995). Cross builds on the work of Howard Gardner which critiques the notion of a single human intelligence, instead suggesting a number of intelligences. Cross suggests the existence of a particular design intelligence.

12 Fleming, "Design Talk: Constructing the Object in Studio Conversations," 46.

locates a design object in a discussion, "performing it" as Fleming refers to it, while the latter assumes the existence of certain design objects and concentrates on exploring their possibilities. This serves to: "position [them] in time, social relations, a system of values, etc.," [13] and to make them real in some sense, rather that just conjecture. Peter Medway,[14] studying conversations in an architect's office over a two-day period, remarks on similar findings, noting in particular the "textual" nature of an architect's work; the interpretation of many interrelated types of media (drawings, faxes, legal documents, conversations, etc.).

For architects or industrial designers, one particular type of "text" dominates design discussions: the sketch. Sketches provide a common reference point to explore and explain a nascent design. The engineering design process, it might be argued, is a rather different affair. Although one still has the "textuality" of a design process, there would appear to be less visual thinking, less "reading" of sketches. Engineers are more adept at "reading" circuit diagrams, or layout schemes, or picking through software. Engineering design projects, often multidisciplinary in nature, lack the sketch "text" as a common means of expression. This multidisciplinary nature of engineering design is suggested by Bucciarelli to describe what he terms "object worlds"—"worlds of technical specializations; with their own dialects, systems of symbols, metaphors and models, instruments, and craft sensitivities." [15] With many disciplines negotiating during the course of an engineering design conversation, it makes more sense to talk about the existence of a number of discourses being conducted. Bucciarelli describes how the existence of different "object worlds" result in what he terms "constraining," "naming," and "deciding" discourses. It is in these episodes that we can begin to get a sense of language being used for very specific functions, as an essential part of the engineering design process.

3 The Design of a Tire Assembly Machine

It is the aim of this paper to try to relate some of the findings about the use of language in the design process to the present data set, using a discourse analytic method. The present data is constituted by five conversational segments, taken from transcriptions of a series of three engineering design meetings held over a six-week period in April–May 1998. The series of meetings concerned the design of a truck tire assembly machine for clients MB.[16] This is a machine that takes tires and wheel rims, and combines them into a completed wheel. This is the kind of operation that is carried out at "Kwik Fit," for example, but as a continuous process and at much greater speed. The enormous size of truck tires also presents considerable problems.

The design project was planned to last from February to September in 1998 and contained a penalty clause. This meant that,

13 Fleming, "Design Talk: Constructing the Object in Studio Conversations," 46.

14 Medway, "Building With Words: Discourse in an Architect's Office," 22-3.

15 Bucciarelli, *Design Engineers* , 62-64, and Bucciarelli "An Ethnographic Perspective on Engineering Design," 162-163.

16 The names of organizations have been changed to ensure confidentiality.

if the company was late delivering the product, it would have to pay compensation for lost production to its client. Progress meetings were held every two weeks. The design content of the project was largely mechanical, but with electrical and software elements as well. Six designers were involved in the project, with approximately twenty-five people in total—including sales, manufacture, service, and management. An average of about eight people were present during the meetings that were recorded.

The company at which the meetings were held is called Chi-Tech.[16] It has approximately one-hundred employees, and is situated on the outskirts of Birmingham in the United Kingdom. Chi-Tech produces test and assembly equipment mainly for the transportation industry. When a vehicle is being assembled on a production line, this sort of equipment helps to test whether it has been assembled correctly and is functioning properly. The total period of study at Chi-Tech was two months, during which time interviews, observation, the attendance at meetings, and the collection of documentation formed a complete data set.

Since tape-recording was not allowed by the organization during meetings, the transcripts were a combination of quickly-taken notes together with the observer's recall, following the meeting, of what was said. Obviously, this means that small parts of the conversation may have been missed, but it is felt that the conversation segments retain much of their original sense and tone. Five segments were selected from the larger transcription of the meetings on the basis of two criteria. The first was coherence; each segment is about something fairly concrete and identifiable as a definite episode in the general flow of conversation. The second was variety; in total twelve segments were analyzed in detail, with the final five being chosen because they allowed a number of different subjects to be covered.

Underlying this approach to the data are two general analytical principles that should be made explicit. The first is that each segment should be a self-contained text with as little as possible reference to the wider context. This automatically ensures that it is the form of the language that is looked at, rather than the specifics of the design problem being solved. The second is that enough "text" should be given to allow alternative interpretations to be made by the reader. It often is the case in analyses of this sort that explanations are given without sufficient text as evidence for the explanation. (And a consequence of taking a discourse analytic approach is that there always are other explanations.) It is felt that enough evidence should be presented to allow (at least in principle) for the possibility of falsification.

4 Five Segments of Engineering Design Conversation

In the following sections, each conversational segment will be presented and then immediately followed by an interpretation of the exchange. Technical terms will be briefly explained in footnotes. The final discussion looks at the general form of the texts, and describes some of the discursive skills demonstrated by the engineering designers.

4.1 Text 1

Mark This weekend we had MB to visit to see about information. […] We were successful about putting more pressure in the tire and we didn't damage the rim. We pointed out that, in production, the machine has to be spotlessly clean.

Steven How did you make the point? I mean, we really need to put it in writing.

Nad And also things like that should go into the manual.

Ian We shouldn't give them the idea that we've solved all the problems. Before we start writing letters, we should be sure to point out that it was a test on their machine.…

In text 1, Mark introduces the subject of a number of "inflation" tests that have been carried out on an existing MB machine, looking at tire pressure in relation to wheel-rim damage. He notes that the tests were "successful"—a positive result. MB has been informed of these results, but with an important caveat: when the new machine is used in production, it has to be "spotlessly clean." Now, most production environments are not "spotlessly clean," so there is a rhetorical sense to the "success" reported to MB. The "success" will give MB confidence about the effectiveness of the continuing design process, but this doesn't guarantee that the machine will work well. For Chi-Tech's purposes Steven, Nad, and Ian are quick to play down the effects of this rhetoric of "success."

Steven asks how the comment of keeping the machine spotlessly clean in production was made, perhaps suspecting only a verbal instruction. He feels that the comment is important enough to be put in writing. Such a move would protect the company from a claim by MB in the event of a breakdown. There is a sense here that Steven doesn't quite trust the "success" that Mark reports; or at least, can see it as rhetoric. Nad adds to Steven's view by mentioning that "things like that should go in the manual." Again, there is a feeling here that problems lie ahead in the use of the machine in a production environment. By including in the manual specific instructions to keep the machine "spotless," Chi-Tech representatives again are covering themselves. By noting that "things like that should go into the manual," Nad's emphasis is, however, on the use of the machine in practice, as opposed to contractual agreements between the organizations. Ian cautions against giving MB the "wrong idea." This is a direct comment about the rhetoric of "success" and he clearly feels that too many unsolved problems exist for such impressions to work in their favor. Giving MB the wrong idea also implies that there is a "right" idea to give, assuming a more complex relationship between the actual process and the customers' perception of that process. Ian also notes that the tests were carried out on "their" (i.e., MB's) machine, preparing the way for the inference that if things do go wrong then it is partly "their" fault.

The specific results of the inflation tests that have been carried out initially are not questioned. Instead, the responses concentrate on either what needs to, should, or shouldn't happen as a consequence of the "successful" tests. Although the three responses are different from one another, they all suggest an understanding of the consequences that reporting such a "success" can bring. It would appear to be experience of similar situations that forms the basis for these imperatives; that is, experience of how one portrays what is happening in the design process to the customer.

There are, then, two things to note in this exchange. First, is the way that rhetoric is used as a continuation of well-defined tests that have been carried out during the course of the design process. Although the tests have yielded positive results—which the customer knows about—the discussion is about how to play down these results in the context of the possible future performance of the machine. The technical and objective results of the tests have been shaded into the wider discourse between design and client. Second is the conception driving this rhetoric, focusing on the differing representations of the design process between customer and manufacturer. The inference is that the manufacturer's representation of the design process is "the truth," while the customer's representation is an impression solely dependent on the information received from the manufacturer. This much is implied in the phrase "we shouldn't give them the idea that we've solved all the problems."

4.2 Text 2

Paul This project is going out one month after the TP project went out 16. I thought we were further ahead at this stage, Mark disagrees, but TP was a repeat job. On this one, we haven't got the advantage of built-in knowledge…

Tony We said at the beginning of this project that we need extra time because of the size of the wheels…

Mark Well, if we work backwards…we've got seven weeks to make all the bits.
[Phil shakes his head]

Tony We knew all this from the beginning, we sat down with Steven…

John It's very tight.

Tony It's more than very tight! On TP, people were virtually dead on their feet, and this is much heavier…

Ian But the positives are that we haven't got so many individual bits, just the sheer size, and that has got to mean more machining time. We've got to be mindful of the fact that we haven't done it before…

Tony It's going to take longer to put this together than TP just because of the sheer size…

The project is running late. The contract has a penalty clause associated with it, and this means that, if the machine is delivered late then Chi-Tech will have to pay compensation. Text 2 tries to establish how long the remainder of the project will take. Paul starts by saying that the TP project was "further ahead" in comparison.[17] The reason for this is that TP was a "repeat job"; itself a copy of a previous job. The difference with the present project is the lack of "built-in knowledge," the tacit knowledge acquired in the doing of something that speeds up the process of doing the same thing a second time. Paul is making the claim that the two projects cannot be compared in this respect. Tony doesn't contest Paul's reasons. Instead, he points out another reason for the difference: "the size of the wheels" to be fitted with tires. He then goes on to point out yet another difference: the present job is "much heavier" than the previous one, and that had been heavy enough ("people were virtually dead on their feet"). Ian stresses another difference between the two jobs, but it is a positive one. There are fewer components. However the "sheer size" of the components means "more machining time." Ian ends by echoing Paul, stressing that "we haven't done it before.…" Tony reiterates Ian's comment about the "sheer size" of the new machine compared with the previous TP job.

Despite all of the reasons for considering the two jobs as different, the past job remains as a reference point in the discussion. The exchange reveals seven conceptions of how the speed of carrying out the present project will differ from the speed of carrying out the past project. Two refer to the lack of tacit knowledge ("we haven't got the advantage of built-in knowledge…" "we haven't done it before"); three mention the size of the new job ("size of the wheels," "sheer size," and "sheer size"); one mentions the weight ("much heavier"); and one mentions the smaller number of individual components ("haven't got so many individual bits"). The evidence suggesting a difference between the two jobs is overwhelming, and there is strong agreement about this between everyone.

Yet the past project, or at least the idea of it, is fulfilling a function here. The common experience—and the level of agreement suggests that it is common experience—is providing a rich means of discussing the present job. However, although there is agreement about the "facts" of the matter, there is not agreement about the suggested outcome. Tony, the manufacturing manager, is using "the facts" to argue for more time than originally was planned for. By

17 The present machine is the same type of machine as the "TP project." They are both tire-assembly machines, however, the TP project was for car tires, which are much smaller than truck tires.

using the pronoun plural "we," he is suggesting that the "extra time" he thinks is necessary for manufacture was agreed on at the start of the project. Others in text 2, although acknowledging the truth of the facts, interpret them slightly differently. John simply says "it's very tight," suggesting that, although it will be difficult, the manufacturing department has enough time to complete the task. Tony has to persuade the others by attempting to exaggerate their common experience ("the facts"). He mentions that people were "virtually dead on their feet," and refers to the "sheer size" of the present project, both statements giving the impression of the present project's impossibility. In the exchange, what is of note is the agreement about certain "facts" and the corresponding differences in interpretation.

4.3 Text 3

Nad We need to move forward…

Mike It's only the circumstances of the drive that is holding me up…

Mark So how long before you start detailing and how long will it take?

Mike Eight weeks…

Mark Two weeks less then, on a heave?

Nad There will be a three week slippage is my guess, based on experience…

Mark We need a month at the end of the job to get the thing working…

Nad We've got to bring that forward, we can't let it slip by three weeks, poor old Mr. Tarling is going to be testing the machine on the ship over to Germany!

Mark Well, we know what happened at TP, we were out there for weeks and weeks…

Mike Hopefully, it won't become a bottleneck, but it's happened on every job I've done…

In text 3, Nad starts with the general feeling that project work "needs" to go further towards the final goal. Mike, being questioned as to how long it will take him to complete a set of concept drawings, answers that it is only external circumstances that are holding him up. Mark then asks Mike how long it will take him to start work on the detailed drawings. Mike is emphatic: "eight weeks." Mark, perhaps wanting a smaller figure and thinking that Mike's estimate has allowed for a large degree of error, suggests that, if he concentrated his efforts, the concept work might be completed sooner. Nad switches the focus to the work plan, commenting that there will be a "three-week slippage"—that the project will take three weeks longer than expected—given his experience with similar situations. Mark points out that a month will be needed "at the end of the job"—which means after the machine has been constructed—before it will be fully functioning.

A few seconds later Nad picks up on his thread again, possibly after having considered the consequences of what his experience tells him. He says that the project cannot afford to slip by three weeks, because that will leave very little time for testing. To support this view he provides a vivid image of the machine being tested on the ship on the way to Germany. Mark reinforces Nad's comment from his own experience ("at TP, we were out there for weeks and weeks") using "we," as Tony did in text 2, to draw in the others present and appeal to some sort of common knowledge or experience. Mike brings the discussion back to the amount of time it will actually take to finish the concept drawings. He hopes that the delay will not prove to be a problem, but thinks that it might be if his experience is anything to go by.

Although the conversation is ostensibly about the time it is taking to finish the concept drawings, it turns into a conversation about the time it will take to finish the project as a whole, a subtle difference. Contrasts are made between planned time, desired time, actual time, and past time. There is the desire to "move forward" past problems that are "holding up" the project; to get through a "bottleneck," Then there is the estimation of how long it will take for the concept drawings to be finished. "Eight weeks" is the estimation, reduced to six on the assumption that what can be done in eight weeks at a certain pace can be done in six at a quicker pace. There might be a "three-week slippage," which has implications for the "month" needed to get the machine working at the end of the project. In previous projects, this task had taken weeks.

The impression given here is one of a malleable time. There is an original project plan, certainly, and a delivery date has been agreed by the customer; but within these "real" constraints, time is being managed and bargained for. Delays are explained as "bottlenecks," and time can be made up by "heaving." There is a feeling of elasticity, with negotiations between different perceptions of timescales in relation to certain tasks. Finally, there are intuitive feelings for how the time will go, accumulated, we might infer, from similar experiences on other projects (and different experiences on similar projects).

At the end of the exchange, it remains uncertain what has actually been decided. The plan appears to have remained the same. What then could be the purpose of such a discussion? There seems a deep relationship between time and experience in the exchange, encapsulated in personal heuristics ("eight weeks can be reduced to six on a heave," "a month is always needed for testing," or "concept drawings are always a problem"). The only way that time can be talked about is either in relation to the past, or in relation to an intuitive feeling about the present situation with respect to the project plan. Time here is not an absolute quantity, but a thing packaged with a particular task, past, or present. What happens in the exchange is that a number of possible scenarios are described. It would seem that the different scenarios illustrate to all present the sense of urgency that is needed. This is achieved not through any sense of control, but through a common understanding arrived at through different perceptions of possible outcomes. Some of these outcomes are baldly stated ("eight weeks"), while others are more creatively put ("poor old Mr. Tarling is going to be testing the machine on the ship"), but all give a sense of what possibilities lie ahead and it is also arguable that this also works to share responsibility between those present.

4.4 Text 4

John Basically we've got a chain conveyor on the walking loom.[18] It's going to be in the attention to detail…

Nad Is that sufficient for a 15-second cycle time? [19]

Brian I have my doubts about fitting it all in.

John We've got it down to 4.2 seconds on a small machine.[20]

Mark And the total machine time is 28 seconds.

John To get the time down, we've been looking at the rim grips, we used to use sixties technology to get the fitting head [21] to come down to find the rim, so it's got to come down slowly to sense the rim. With a servo motor, you can come down quickly.

Nad It's important to remember that, in everything we do, we don't forget the cycle time…

John Terry agrees that the fitting time is very tight, I personally can't see why you can't fit at increasing speeds…

Brian In theory I agree with you but, at increasing speeds, you might spin on the rim and leave the tire behind…

Text 4 is about the solution that has been used to converge on a key performance criterion: the cycle time. Initially, John describes the basic technology of the new machine ("a chain conveyor on the walking loom") suggesting that it simply needs refining to meet the key performance criteria: "it's in the attention to detail…". Nad questions whether this solution will meet the performance criteria, while Brian expresses stronger reservations ("I have my doubts about fitting it all in"). John replies by saying that the level of performance required has been reached on a previous, smaller machine which, together with the assumption that the big machine will behave in the same way as the small machine, suggests that the level of performance required can be reached. John then goes into more detail about specific refinements that have been made to the original level of technology, backing up his earlier "attention to detail" comment. He suggests that a servo motor will solve the problem. A little later, he reveals a slight difference in opinion about

18 The chain conveyor and walking loom are a mechanical technology that allow a sequence of operations to be carried out through the tire-assembly machine. Wheels are metaphorically walked through the machine.

19 There are three times that figure in the dialogue. "Cycle time" is the rate at which the machine produces assembled wheels and tires. "Total machine time" is the time it takes a separate wheel and tire to become an assembled wheel and tire. "Fitting time" is a proportion of the total machine time, and is the time taken to complete the sub-task of fitting the tire to the rim.

20 The "small machine" refers to the previous TP project, which assembled car tires.

21 The "fitting head" is the part of the machine that fits the tires to the wheel rims. This is a piece of equipment that descends to complete the operation once a wheel rim is in place beneath it. It completes the operation by turning the rim so that the tire gradually works its way onto the rim.

the proposed solution between himself and Terry (who is not present). John reiterates that he can see no problem fitting the tire at increasing speeds, while Terry obviously has told John how "tight" he thinks the tire fitting will be. Brian takes Terry's line and explains why the machine might not work at increasing speeds: "you might spin on the wheel."

Will the proposed solution work? No one says that it won't work, yet reservations are expressed about whether it will meet the "tight" performance criteria. The proposed solution is a refined and scaled-up version of solutions that have been used on previous projects. John sees no problem with this scaling up. Terry and Brian, however, are not so confident. During the exchange, John constructs a verbal "model" of this solution. All are agreed on this model—no one is directly disputing the solution principles—yet the consequences of this model, and the issue of whether or not it will meet the performance criteria, are the subject of a difference of opinion. The construction of this "verbal model" is possible only because of the familiarity everyone present has with both previous designs and the relevant technological principles, a common knowledge existing among those present. Out of these basic "materials," John is able to construct, in a few short utterances, a model of his proposed solution. He creates a common "object" for analysis.

Such a situation might seem highly specific. The design is at a very particular stage of development, and it is unlikely that it would be questioned in any fundamental sense. It could be argued that other participants may be keeping quiet about criticisms they may have. Yet the "method" of drawing on common experience to "sketch" a solution appears to be a familiar one. A way of quickly exploring a number of implications and consequences should a certain solution be adopted. There is a kind of tacit acceptance here, a suspension of disbelief among those conversing. There also is a sense in which the participants are "using" this "object," and commenting on its functioning. The key point is that the created conversational "object" is only a vehicle to explore decisions that have to be made. It is a hypothesis that will help to determine key indicators of success or failure.

4.5 Text 5

John Well, on the limit switches[22] MB was surprised that we suggested proximity switches. I said that they're standard at Chi-Tech. MB said proximity switches are expensive compared with reed switches, but I don't really mind…

Brian We've found reeds to be unreliable in the past…

David We changed a few on Tudor[23] because there were failures…

Brian They come loose and fall off, but there are applications where they can be used…

22 Limit switches are a way of detecting whether a moving component has reached its intended destination. There are various ways to do this, but two well known methods are: proximity switches which detect by magnetic induction, and reed switches, which detect by physical contact.

23 Tudor is another previous project.

Ian My guiding principle has always been, where the machine is concerned, not to use proximity switches…
Mark Ninety percent at MB are reed switches, but they're not Festo ones.
Ian Festo[24] are cheap and cheerful.

John introduces the topic of limit switches in Text 5. He mentions that MB was surprised about the choice of limit switch ("proximity switches") because they thought that they were more expensive than reed switches. Although the "standard at Chi-Tech" is the proximity switch, he ends rather neutrally by saying that he doesn't really mind what they use. There then follows a series of comments about the performance and application of reed switches, as compared to proximity switches. Brain says he has found them "unreliable," David says that on a previous project, they failed. Brian remarks on the way that they usually fail: "they come loose and fall off," but also adds that there are some things which they can be used for. Ian mentions that his "guiding principle" is "not to use proximity switches where the machine is concerned." This puts an emphasis on not using one thing (proximity switches), rather than positively using another (reed switches). We then get the fact that ninety percent of the switches at MB are reed switches though, perhaps significantly, not Festo reed switches. Ian underlines the significance of this remark by stressing that Festo reed switches are "cheap and cheerful."

There is a basic taxonomy of types and instances in the conversation. First of all, there are the types of limit switch: proximity switches and reed switches. Then there is an instance of a type of reed switch: "Festo reed switches." The conversation circles around evaluations, opinions, and experiences of different types of detection mechanisms and products. Everyone (including MB) seems agreed that a decision has to be made between reed switches and proximity switches. To aid this decision-making process, the outstanding attributes of each switch are offered. Reeds are "unreliable," they have failed in the past, they "come loose and fall off," they "can be used" in some applications, and "ninety percent of switches at MB are reed switches." Proximity switches are: "expensive," they are "standard at Chi-Tech," there are intuitions—"guiding principles"—against using them, or in a similar vein, "surprise" at using them. Then there are the particular attributes of Festo reed switches. They are not used at MB, and they are "cheap and cheerful."

Text 5 is somewhat ironic in that it is concerned with deconstructing the capacities of existing technology in the process of constructing the capacities of new technology (i.e., the tire assembly machine). Such a discussion implies that the capacities of the new technology rely to some degree on associations with the perceived capacities of its components. "Cheap and cheerful" components

24 Festo is a manufacturer of reed switches.

might then result in the final product being perceived as "cheap and cheerful." The irony is that, in discussing a component's capacities, the people present are denying the possibility of that component having actual or objective capacities while simultaneously attempting to construct the actual or objective capacities of their own product. The decision to use a certain component, then, is a complicated act of judgment. There are objective elements involved, certainly: sizes, materials, and also functions; but there also is a large degree of personal (and hence in a group situation aggregated personal) preference. These preferences are formed through both particular experiences ("they come loose and fall off") as well as more nebulous "guiding principle." There is a case for considering these preferences as aesthetic judgments.

It is of note that the inquiry into the suitability of limit switches was triggered by the "surprise" of MB. This surprise has caused an explicit examination of the reasons for the preference of a particular component; preferences that would, we might assume, have remained unquestioned otherwise.

5 Discussion and Concluding Remarks

It is self-evident that the five conversational segments took place over a bedrock of common assumptions and experiences. This clearly enables the participants to forego lengthy explanations, and to talk quickly about the current situation. Common assumptions concentrate more on the technical properties of the design—often, in the text, it was clear that a particular way of solving the problem was not questioned—while common experiences focus more on the past as a means of exploring the present situation. This illustrates how much the current design process depends on the past experiences of those present, which also shows just how unique a situation it actually is. In all five texts, we have noted how past experiences have acted as touchstones during the course of the meeting. In effect, this situates the present design within a web of connections with past designs. In text 2, for example, Tony remembers that: "on TP, people were virtually dead on their feet" while, in text 3, Mike recalls: "it's happened on every job I've done." To those present, such touchstones are, in many ways, an objective reference for the situation in hand. That is to say, they are "objects," perhaps "discursive objects" might be a better phrase for interpretation and analysis. Fleming [12] notes two kinds of discourse in the design process. He observes: "object-laden" talk—situating objects within a discursive context; and "language-laden" talk—explaining the consequences of certain objects being the case. It is notable that, in this professional design situation, the talk seemed heavily biased toward the language-laden end of the spectrum.

Common assumptions and experiences ensure a large level of agreement but, in every text, there always was some level of disagreement. That is almost a prerequisite for a "discussion" taking place. This disagreement often was not, as one might have imagined in an engineering design context, over technical matters, but about the *consequences* of certain "facts" being the case. In text 1, the discussion was about how to represent the ongoing design process to the client; and in text 4, about how a certain solution would perform. In these discussions, the design engineers displayed a certain intuitive artfulness; their technical skill as designers playing second fiddle to their ability to make a convincing interpretation of the situation.

Such an ability is not one that usually is associated with engineering designers, and perhaps not even an ability they themselves are explicitly aware of. It is, nevertheless, an important ability as these texts show. The skill in constructing an effective argument from a few well-chosen words and references is one more akin to a politician than to an engineer. This is an important point. In the texts, the designers used several mechanisms to get their version of the consequences of a situation accepted by the meeting. One mechanism is the use of exaggeration and imagery. In text 2, Tony mentions that, in the past project, similar to the current project, people were "virtually dead on their feet." In text 3, Nad remarks on the limited time available by suggesting that the "poor old" test engineer "will be testing the machine on the boat on the way over to Germany." Both are effectively illustrating serious points. Another mechanism was the suggestive use of the pronoun plural "we." In text 2, Tony states "we knew all this from the beginning…" and, in text 1, Mark remarks "we were successful…. Both are trying to imply a *common* agreement about what has happened, in effect sustaining their "argument" for as long as possible. There also is an implied objectivity about past experience, something that is extremely difficult to refute directly. In text 5, Ian cites his "guiding principle" as a reason for not using a certain component while Brian has found that certain components "come loose and fall off…." In text 3, Mike mentions that something has "happened on every job I've done." Such remarks have an important rhetorical function in putting an argument across to the others.

If all of these mechanisms add up to a kind of "rhetorical ability" of engineers in the current study, then there is one more distinct ability to note. That is the critical ability; the ability to recognize, analyze, interpret, and aesthetically judge an object. Such an ability was demonstrated in Text 5, in which the technological capacities of sensing equipment were constructed, together with the associations of meaning they held for the meeting. It is here that one gets the feeling that many decisions are made just as much on aesthetic grounds as on purely objective or technical grounds. Aesthetic is used here to refer to an individual expression of preference rather than anything solely visual in nature. This is a surprise given the supposed "objective" nature of engineering design (as illustrated by the quote at the beginning of the article [7]).

In design disciplines apart from engineering, graphical representations play a much larger "modeling" role in design discussions. In architecture, graphic design, or industrial design, a design is sketched, drawn, and modeled in a series of "physical" ways of expression. For these disciplines, it is easy to see how these physical objects can be "performed" in Fleming's terminology: [12] by pointing, gesture, and explanation. Once they have been accepted as valid objects for discourse, the consequences that derive from a performance then can be drawn out. It would seem as though engineering designers are achieving exactly this result, but by using words instead of graphical representations. That is to say that engineers use words to model and explore consequences. The words provide a sort of collective sketching function that is not possible in a graphical representation, simply because of the nature of the task. These words, these very particular words, can remain ambiguous while still suggesting possibilities—just as a quick sketch from an industrial designer might suggest a number of possible forms and hence, implications. And, just as industrial designers have a common sketching vocabulary, the engineer's words only properly function on a basis of common knowledge and experience. In other words, they provide a first level of prototyping.

Could it be that this kind of conversational function is found not only in engineering design and design in general, but also in other areas of professional practice? One of the essential aspects of design that we mentioned at the beginning was that design conversations are conversations about things that don't yet exist. It may well be that there are a number of possible parallels with other conversations concerning, for example, the future, or a future state of affairs. Schön [25] argues that design-like behavior forms a problem-solving prototype for much professional action, while Cross[11] has suggested that designing (and, we might infer, design talking) meets criteria to consider it as a separate kind of intelligence. This paper, however, has attempted to show how advanced this kind of talking is for engineering designers. This, we have proposed, might be because of the largely non-graphical nature of the task environment. It would appear that the typical analytical ability of the engineer—an ability that seems to be predicated on the idea of an individual "object world"[15]—also brings with it a skill in using and manipulating language—a strongly social ability.

There are educational implications here. If such a skill is something that experienced design engineers can perform without training, then explicitly nurturing that skill in students with a low level of experience might be worthwhile. The texts presented in this paper would point to both education in rhetoric and aesthetics as important areas of curriculum development in engineering design. It is highly likely that this knowledge could help engineers to

25 D.A. Schön, *The Reflective Practitioner,* 77.

become aware of the varying types of reasons, information, and experiences that design decisions are based on, and help to dispel the myth that all engineering information is somehow scientifically based.

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