Communication Literacy for 21st Century Engineering Education

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Abstract

This paper presents several key issues that are contained in a communication curriculum designed to address critical issues facing engineers, and expand traditional material typically used for engineering education. Specifically, I will overview the complexities of the manager-engineer relationship, then discuss visual and statistical thinking as it relates to display of evidence for decision making. To illustrate the critical nature of these and other key communication skills, several case-studies are presented where engineers' failure to communicate effectively resulted in significant negative consequences: most notably the NASA Space Shuttle Challenger disaster. The full curriculum also covers basics of oral and written communication, language use, listening, and interviewing. It is supported by reading materials that contain the charts and other visuals described below, and by a web site: *http://dlc.utsa.edu/levitt* where full details contained in the curriculum can be found and used. This curriculum has been successfully implemented in an Introduction to Engineering course taught via distance learning.

I. Introduction

The importance of communication skills for practicing engineers is widely recognized, yet not fully addressed in the typical engineering curriculum. Communication can be an engineer's strongest ally or his/her worst enemy. The safe return of the crippled Apollo 13 spacecraft marked both engineering and communication success. The explosion of the space shuttle Challenger was the price of failure. As I will further illustrate shortly, failures to communicate effectively can lead to disastrous consequences.

The Engineering Criteria 2000 promulgated by the Accreditation Board for Engineering and Technology, Inc. (ABET) offers an opportunity for innovative undergraduate learning. The Accreditation Board for Engineering and Technology's *ABET Engineering Criteria 2000* program outcomes and assessment states that
"Engineering programs must demonstrate that their graduates have:
a) an ability to apply knowledge of mathematics, science, and engineering;
b) an ability to design and conduct experiments as well as to analyze and interpret data;
c) an ability to design a system, component, or process to meet desired needs;
d) an ability to function on multidisciplinary teams;
e) an ability to identify, formulate, and solve engineering problems;
f) an understanding of professional and ethical responsibility;
g) an ability to communicate effectively;

h) the broad education necessary to understand the impact of engineering solutions in a global/societal context;
i) a recognition of the need for and an ability to engage in lifelong learning;
j) a knowledge of contemporary issues; and,
k) the ability to use the techniques, skills, and modern engineering tools necessary for engineering practice"[1].

The first three criteria are standard engineering skills. Engineering educators realize these skills are not sufficient for successful careers in engineering. It is important to note that several of these criteria directly require *communication skills*. From a practical standpoint, I like to point out to students that recruiters consistently claim poor writing skills as the number one reason why people do not get interviews. Further, poor communication skills are the number one reason why people are not hired after an interview – and poor listening is the number one reason for failure during an interview[2].

Norman R. Augustine in a prescient article published in ASEE Prism, February 1994 asserted the greatest challenges to engineers in the future would come from non-engineering sources[3]. Hence, he coined the phrase Socioengineering Age. "In the Socioenginering Age, engineers many achievements are largely taken for granted and our occasional failures draw intense public criticism." He goes on to say, "the term socioengineering combines elements of a traditional engineering education with the far broader skills needed to prosper in the twenty-first century." Eleanor Baum of the Cooper Union for the Advancement of Science and Art suggests that "We will expect engineers to have a background well beyond technology and science…the biggest change for universities will be to turn engineering into a liberal art"[4]. Baum claims engineers are hired for their analytical and problem-solving skills more than their technical skills. Yet communication skills are equally important because *information becomes knowledge* only when conclusions drawn from analyses and potential solutions to problems are *effectively communicated* to those who need to make decisions or implement solutions. Sister Joel Read, President of Alverno College states that "When problems arise in the workplace, it usually isn't because people don't have the right information. Things go awry when communication breaks down – often because someone fails to see something from a different perspective"[5].

II. Brief Case Examples

An engineer was a partner in a small construction company working on the construction of NASA headquarters in Houston, Texas. This was an enormous project with many contractors and on a fast timeline. A backhoe operator working for the company was killed when he dug into a cable box that was not shown on any plans: the existence of the box was not communicated to the people doing the work. The cable box was not shown on any plans because it was connected to Top Secret facilities and therefore the cable box was also considered Top Secret. Levels of bureaucracy and aggressive timelines foster errors.

A consulting firm was accepted as a contractor for the Corp of Engineers to do site work, drainage, and building on a military base. The guidance given during negotiations was to do building similar to existing structures on the base. These were permanent, mostly brick buildings. The contract called for milestone reviews at 35%, 90%, and 100% completion, with payment at each step for the work done. At the 35% review, when the building was designed and plans ready, the Corps of Engineers project manager informed the consultants that the building was to be a temporary construction of Butler Building type. The consultant was paid the 35% fee, and the work had to be redone at taxpayer expense.

A consultant tested dirt at the San Antonio Alamodome construction site. The consultant informed various parties of the potential problems: the dirt was contaminated with hazardous materials. This information was either not understood or ignored, and the dome was built. The existence of the hazardous material finally became public, resulting in a costly, time-consuming remedy and damage to many professional reputations.

Engineers at Ford sent a memo to management stating that an $11 modification would make the Pinto gas tank safer. The decision, however, was viewed as properly a decision for managers, not engineers. This is consistent with the widespread attitude that engineers are paid to render advice to management, but that their perceptions should not prevail over executive decisions. The decision was later criticized because "it did not consider litigation, recalls, and bad publicity which have already cost Ford over $50 million"[6].

As early as 1984 engineers at Morton Thiokol International (MTI) suspected the danger of cold temperature on the O-ring seals[7]. Cumulatively, evidence of O-ring damage at cold temperatures built and led engineers to conclude that there was a severe danger of O-ring failure below 53^0F[8]. The night before the Jan. 28, 1986, launch of the shuttle Challenger, predicted temperature for the launch was 26^0 to 29^0. Concerned that the O-rings would not seal properly, engineers at MTI opposed the launch. They faxed 13 charts to NASA officials and held two long telephone conferences. Ultimately, NASA managers felt the evidence presented by the engineers was inconclusive and recommended that the launch proceed. That morning the Challenger blew up and seven astronauts died.

What do all these cases have in common? They all illustrate fundamental communication problems. Bob Sohn, Attorney at Law, mediates these types of problems and claims, “When you pull the thread all the way back to the beginning, communication problems (omission and commission) are the root cause virtually every time.”

Communication is a complex process, subject to individual perceptions and interpretations of meaning, and thus *ripe for misunderstandings*. I contend that when two people interact, there are at least *eight simultaneous conversations* occurring:

- What I say.
- What I mean by what I say.
- What you hear.
- What you think I mean by what I say.

And, of course,

- What you say.
- What you mean by what you say.
- What I hear.
- What I think you mean by what you say.

With this level of complexity, it is clear that we cannot take for granted our ability to communicate effectively. More importantly, failure to communicate effectively can and does result in significant negative consequences. I now turn to several key concepts from the curriculum that will help aspiring and practicing engineers improve their communication skills and hopefully avoid the consequences of misinterpretation and misunderstanding.

III. Manager-Engineer Relationships

Many communication problems stem from the manager-engineer relationship. There are often serious conflicts over decision-making prerogatives and willingness to risk making decisions. These conflicts result from differences in educational backgrounds, socialization, values, and perspectives. Many managers are not engineers and thus do not have engineering expertise. This makes communication even more difficult. A brief overview of the functions of engineers and managers is useful to delineate the problems[9]. Engineers obtain and use technical knowledge in creating products and processes that add value to an organization. They tend to place primary emphasis on safety, and be inclined toward caution; preferring to err on the conservative side. Managers, on the other hand, "are more likely to be governed by the standards that prevail within the organization…and are primarily concerned with its present and future well-being…managers might be more willing than engineers to reduce quality or safety in favor of such matters as cost or marketability"[10]. This suggests a distinction between what has been labeled a "proper engineering decision" and a "proper management decision" – and further that "management standards should never override engineering standards when the two are in substantial conflict, especially with regard to safety and perhaps even quality"[11]. The case studies presented here illustrate that managers and engineers often do not restrict themselves to their proper roles. The typical authority structures in business and governmental organizations make it likely that managers will overstep their management role and make decisions that should be made by engineers.

These often conflicting functions involve different perspectives about decision-making, but also different communication styles. "Engineers sometimes complain that they have to use oversimplified language in explaining technical matters to managers and that managers do not really understand engineering issues"[12]. Engineers want to tell all they know, giving many details and facts, and are also inclined to want to draw their own conclusions from data. Managers, on the other hand, typically want the bottom line, condensed into a summary conclusion.

The presentation of data by MTI engineers to NASA officials is illustrative of this disconnect between communication styles. Further, research has shown that bad news is often not passed up to higher levels in an organization, and even when it is, people are less likely to believe it than good news[13]. Hierarchical relationships where contracts need to be protected exacerbate this tendency. An internal MTI memo from engineer Roger Boisjoly to management stated that if immediate action was not taken to solve the O-ring problems "we stand in jeopardy of losing a flight along with all the launch pad facilities"[14]. The complete memo is insistent, direct, and emotional.

When communicated upward to Marshall Space Center managers (only in response to specific questions from a Problem Review Board), the language was softened to "MTI has no reason to suspect that the primary seal would ever fail after pressure equilibrium is reached [but that] secondary sealing…cannot be guaranteed"[15]. The entire memo "gives just the facts, providing little interpretation…people who read it were uncertain about what it meant"[16]. This unclear language makes it easier for decision-makers to lean further toward the direction they or others are already predisposed to take.

There are times, however, when managers are engineers by training, as was the case with the Challenger accident. Even with common training and many of the same facts at their disposal, the engineers and managers *interpreted* the facts differently because of their very different points of view. Where you stand depends on where you sit. Engineers place primary importance on safety. "They are inclined to be cautious in this regard, preferring to err on the conservative side"[17]. On the other hand, managers are often subject to political, economic, social, and other pressures that influence their perspectives. There were substantial pressures to launch Challenger as quickly as possible due to various public relations and media events[18]. R. K. Lund, MTI's Vice President of Engineering, had initially recommended against the launch. During the final vote among MTI's vice presidents, Lund was asked to take off his "engineering hat" and put on his "management hat." "When Lund changed his role, he changed his position"[19]. Once again, aggressive timelines and levels of bureaucracy foster decision-making errors.

"Knowledge is not simply seeing facts but rather interpreting them…communication is not just shared information; it is shared interpretation…Communication about O-ring problems, then, had to overcome the barriers to moving bad news between engineering and management sub-cultures, up through organizational hierarchies, and out to other organizations. Under these circumstances, it is hardly surprising that the communication failed"[20].

In the Ford Pinto case, "the decision not to add the part…was not an engineering but an executive decision…[engineers] do not have the obligation to insist that their perceptions or their standards be accepted. They are not paid to do that, they are not expected to do that, and they have no moral or ethical obligation to do that"[21]. Unfortunately, many engineers tend to buy into this philosophy.

The prescription that especially in matters of safety, engineers should have certain prerogatives in decision-making that managers should not violate is again noted. In addition, it is critical that engineers learn to communicate effectively with managers by communicating *like* managers: using brief, concise language with feeling and decisive conclusions. Managers must *listen* to engineers from an engineering perspective. Changing individual communication patterns, however, is insufficient. The *system itself* must change to be porous enough to accept open communication from people at all levels of a project. Engineering designers are a component of a set of interdependent relationships that have to work well together. Part of good design is an ability to function on multidisciplinary teams (ABET criterion d) – setting up relationships and expectations of different interdependent people. The key to success is early recognition of symptoms, and creation of a communication climate where problems of mutual interest can be addressed, and action taken before problems escalate. Levels of bureaucratic filters must be removed and direct lines of communication between those with the information and those making decisions established.

IV. Displays of Evidence

Even if managers at NASA had been predisposed to accept the engineers' conclusions, the displays of evidence used did nothing to help their arguments. A key point is that when an audience is predisposed *against* a position, as managers at both MTI and NASA were, the communication must be *much more effective*. "On the day before the launch of Challenger, the rocket engineers and managers needed a quick, smart *analysis* of evidence about the threat of cold on the O-rings, as well as an effective *presentation* of evidence in order to convince NASA officials not to launch"[22]. They succeeded in their analysis. The exact cause of the accident was predicted. They failed in their presentation. Managers ultimately felt the evidence presented by the engineers was inconclusive and recommended the launch proceed. A few of the problems with the presentation are summarized here:

- The data faxed to NASA were presented in 13 charts. The charts broke the evidence up into "stupefying fragments."
- The charts gave no indication of the names of the people who created them. No credibility could be established, provoking doubt about the evidence.
- The second chart presented (after the title chart) provides six types of O-ring damage, but the chart does not provide *any* data about the possible *cause*, temperature. Chart junk (typographical problems, handwritten corrections, etc.) obscured presentation of the critical cause-effect relationship between temperature and O-ring damage. Indeed the second chart devotes a full column to Nominal Diameter of the rockets, which are *all the same*! Thus this column does not even represent a variable.
- Several charts prepared later for testimony to a presidential commission still failed to present the evidence. They used icons of rockets with various codes indicating severity of O-ring damage. The first of these charts has the legend interpreting the coded marks. There are two major problems here: first, the opening chart shows *no rockets with any O-ring damage*. Second, *none of the subsequent charts has the legend*, thus the viewers are left to memorize the coded marks.

- On another chart that depicted rockets and observed O-ring damage, the rockets were ordered by launch date rather than temperature, again concealing the critical cause-effect relationship. If the rockets are ordered by temperature, the relationship is much more readily apparent.

Several important conclusions about display of evidence can be drawn from this example. First, "there are right ways and wrong ways to show data; there are displays that reveal the truth and displays that do not"[23]. Second, "Good design brings *absolute attention* to [the most critical] data…these problems are more than just poor design, for a lack of visual clarity in arranging evidence is a sign of a lack of intellectual clarity in reasoning about evidence"[24].

V. Conclusion and Evaluation

This paper represents only a small part of the entire communication curriculum, but highlights key concepts engineering practitioners and students should assimilate. The web site containing the curriculum offers access to all interested in exploring these issues and further developing their communication skills. Student response has been very positive. I offer a few illustrative comments:

- "I was not aware that communication was so important. You gave me more than a few useful tips that I have been practicing since your presentation."
- "I found the information to be very helpful in determining what I need to practice and touch up on in terms of my communication skills. Your emphasis on writing skills being so important has convinced me to touch up on mine."
- "The most important thing I learned was the importance of clear and simple communication. I believe it will be important to be able to 'translate' technical language into something everyone can understand. Making the point of a presentation as simple and brief as possible is important."
- "I had forgotten how important these skills were in critical, life-changing situations. The aspect of decision making was very useful."
- "If I had to tell a friend about the message I received it would be how each day I am challenging myself to become a better listener."

I now put forth the challenge to all engineers and educators.

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