Session 2642

Connecting What Engineers Do with How & What They Are Taught

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Abstract.

The traditional literature describes engineers as creative people who design artifacts. They use knowledge of nature's physical laws and the properties of materials to create things that meet human needs and wishes. While accurate in an abstract sense, this description is discordant with the minutia of an engineer's daily work. When life is a series of inconclusive meetings, dangling conversations, and incomplete to-do lists, it is hard to remember that you are grappling with the physical laws of nature.

Adapting industrial engineering work-study practices to the office, ten engineers in six organizations were observed for a continuous one-week period. The resulting activity breakdown revealed that communication, data collection, and historical research was much more prominent than calculation, experiment, and design. A synthesis of the data suggests that the appropriate descriptor might be that, "engineers orchestrate the production of things."

This paper focuses on outlining the implications of these results for the education of engineers and of engineering managers. The paper also discusses the study methodology, and the results from the initial data collection. One goal is to present the methodology for comment that will help us improve it. A second goal is to identify colleagues who are interested in working with us to expand the range and number of engineers and organizations that are observed.

Engineers defined.

In 1828, the British architect Thomas Tredgold defined engineering as "the art of directing the great sources of power in nature for the use and convenience of man. (Kirby, et al)" By the 1940's the definition had evolved to a functional one, and Hoover and Fish in *The Engineering Profession* listed the engineer's primary functions as: designing, constructing, producing, operating, and selling. Today, the Alberta Association of Professional Engineers *Guide to Occupational Specialities in Engineering* lists: research, design, development, testing, procurement, production, construction, operation, administration, and teaching as distinct fields of engineering practice.

Writers on engineering often equate engineering with design. It can be argued that design is the core activity, and that all other activities such as testing, procurement, construction, etc. are supporting or complementary. However to make the design function, or designers, paramount is to deny the reality of most practising engineers. Figure 1, together with the accompanying table, lists the percentage of engineers by job function.

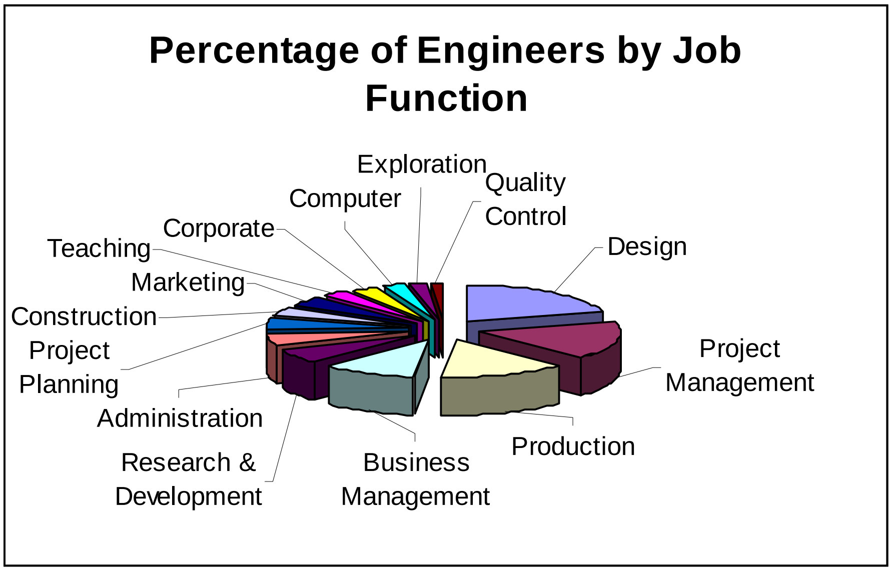

Figure 1 from the Canadian Council of Professional Engineers (CCPE) Task Force Report on the *The Future of Engineering,* July 1988 page 32

Job Function	%
Design	20.43
Project Management	16.67
Production	14.58
Business Management	10.82
Research & Development	6.23
Administration	5.64
Project Planning	4.83
Construction	4.51
Marketing	4.36
Teaching	3.12
Corporate	2.87
Computer	2.55
Exploration	1.93
Quality Control	1.42

Design is the job function reported most frequently by these engineers, but it is still only 20%. Four times more engineers see themselves as doing other things. Also, it leads to the question, “what is design?”

A typical design definition is that provided by the MIT Committee on Engineering Design which is, “Engineering design is the process of applying the various techniques and scientific principles for the purpose of defining a device, a process or a system in sufficient detail to permit its physical realization." This seems a lot like the earlier mentioned Tredgold definition of engineering but without the "use and convenience of man" part.

What do engineers do?

The definitions and functions do not describe the actual minutia of the engineer's job. It is difficult to visualize exactly what one is doing when designing, planning, or fulfilling any of the other functions. However, what engineers do is of considerable concern to engineering educators. Adequately conceptualizing and describing a career is an obvious pre-requisite to developing an educational program for it.

We have undertaken an observational study of engineers in practice. Rather than asking, we would observe and record, and in this way develop an activity-based definition of engineering. This activity-based definition is more inclusive than a common categorization of the activities of engineers into engineering or non-engineering. Non-engineering tended to be administrative, clerical, procurement, coaching, and similar activities which, as the earlier function list implies, the profession regards as engineering.

More relevant, given that consulting firms employed most of the engineers studied, the time spent on these activities was billed out at engineering rates. Thus, for purposes of this study, it was decided that if an engineer was performing an activity as part of their paid employment as a member of an engineering firm, then the activity was engineering.

In short, we chose to define engineering as work that engineers do.

Research Method

As stated before, the methodology focused on observing engineers at work. The method was for a student observer to spend all (or as much as possible) of the working day with an engineer, recording all the activities that the engineer engaged in.

The research method is linked to the preliminary stage of this research. For example in recording all of the engineer's activities, no categories were used. It was felt that developing categories first could bias the data by causing the observer to fit the observations into predetermined slots. In later stages we expect to develop categories so that consistency across observers will be easier to maintain.

The observation period chosen was one week. Observations were taken at the engineer's office, so that work-site time and work at home during the evening and on weekends was not detailed. Off-site work done during the working hours was, where possible, noted and recorded. Travel to and from the job site often accounted for the bulk of this time. Reported work done after hours at home, or returning to the office, was noted and included but not observed. We note that this time is likely to be distributed somewhat differently than the observed time.

So far, 10 case studies have been conducted. These have been done in Edmonton, and

Dallas and we are beginning to observe engineers in Anchorage as well. They are detailed in Table 2.:

Table 2. Engineers who were observed.

The A and B designations are used to distinguish two engineers in the same company .

Field	**Rank**	**Firm type**	**Firm size**
Geotechnical Engineer –A	Senior	Consulting	Medium
Project Engineer	Senior	Construction	Large
Civil Engineer	Senior	Consulting	Small
Structural Engineer	Senior	Consulting	Small
Systems Engineer – A	Intermediate	Computing Services	Large
Systems Engineer – B	Intermediate	Computing Services	Large
Design Engineer	Intermediate	Gas Utility	Large
Project Captain	Intermediate	Telco	Large
Municipal Engineer	Intermediate	Consulting	Large
Geotechnical Engineer –B	Junior	Consulting	Medium

Data Analysis

The general methodology for analyzing the written observation data is based on the social sciences research concept of Grounded Theory. That is by starting with data systematically gathered, it is possible to evolve theory through the continuous interplay between analysis and data collection (Strauss & Corbin).

Subsequent to each observation period, the written record were then subjected to a preliminary analyzes and categorized. The first item of interest was the basic time allocation. The following descriptors covered the observed activities:

Desk Work conducted while the subject is sitting at their desk and working (reading, calculating, writing, etc.)

Computer Work done on a computer. (Calculation, use of software, drafting or writing.)

Conference A conversation, consultation, design briefing, instruction or approval interaction between the subject and one or more other people. Usually conducted in the subject's space and at the subject's desk.

Meeting A scheduled meeting

Phone A conversation on the telephone, usually from the subject's desk.

Away Subject is out of observation range. (Often conferring with others in the office). In the early stages of observation the observers were reluctant to be either disruptive or intrusive. Thus, when the subject left his space they were often not followed and opportunity did not arise to query them later.

Travel Work related travel, usually to or from a job site or client's office

The data increased in richness as the study has progressed. During the early observations, the observers were timid and anxious not to be intrusive or disruptive. Thus the observation was done from a distance. Either adjacent cubicles or across the hall. This was found to provide reasonable observational activity data about what the subject was doing but did not provide much for content analysis. For example, the subject was writing or calculating, but we did not know what they were writing or calculating. Or the subject was phoning, but we did not know the nature or topic of the phone call. Consequently, this early data lacks depth and has gaps that could only be catergorized by the Away grouping. In the later studies the practice of "shadowing" the subjects was adopted and consequently the data increased in richness and the amount of time allocated to the Away category greatly diminished. There is still an element of Away in the data because total shadowing would be to intrusive and the observe would become a causative element in the data. It is one thing to ask a person to accustom themselves to an observer sitting quietly in the corner of their cubicle—it is quite another to ask them to function normally when someone is following them everywhere they go.

The preliminary results analysis is focused exclusively on the activity data and an interesting pattern is emerging. First, if we take out the time allotted to descriptors, Away and Travel, the interactive activities of Conference, Meeting and Phone generally take over one half of the time. Also, with the exception of the two System Engineers, the time spent on computer was the least of all the activities.

While not detailed here, preliminary analysis indicates that seniority of rank or position has surprisingly little impact on these results. This is somewhat counter-intuitive since many assume that meetings and interaction are very common in more managerially focused positions, but that junior engineers and intermediate engineers have a different time mix. Our preliminary results indicate that the interactions are less formal and involve smaller groups, but that the mix is surprisingly similar.

Educational Implications

Even these preliminary results should cause us to seriously examine our education patterns. The general college engineering curriculum is based upon individual effort and doing design through calculation and analysis. The observed activity patterns of the engineers were characterized by interaction with others and by doing design through accumulating information from others. This suggests that the practicing engineers are using a skill set very different from that taught by the colleges. This is particularly important since most of the engineers included in this study would describe themselves as "design" engineers.

In examining the implications of these results, we acknowledge that the results are tentative. Nevertheless, we do have some suggestions to advance. These suggestions touch upon both the content of a typical undergraduate engineering curriculum, and the process of administering, teaching, and graduating students in such a program. These suggestions are also based on our work to modify the teaching of graduate engineering management (Eschenbach and Ra, 1997).

Before students arrive on campus the selection process has begun to rely on the stereotype of what engineers do. Admission officers focus on individually achieved math scores on aptitude and achievement exams. Perhaps interviews should be used to judge abilities and potential in interpersonal communication.

Once they have arrived, then learning could become more group and less individually focused. Today engineering students often encounter groups only 1) as informal, self-formed study groups, 2) as lab groups, and 3) as senior design projects. The first is often a survival tactic which at least a few instructors have been known to resent for protecting weaker students who should be "culled" from engineering. The second is often a money driven device to allow colleges to function with less expensive facilities. Little or no effort is expended on using this as an opportunity to teach and develop skills for working in groups. The third is particularly incongruous since design is often envisioned as the most individual of engineering activities.

We suggest that the most effective tactic for changing this individual model would be to introduce a required, freshmen-level course in group processes. This should include diagnostics for individual students, conceptual models on group processes, data on group performance, and practice in group development. This course could be easily combined with introductory courses that focus on bringing engineering into a lower division curriculum that is often dominated by mathematics and the sciences – since such courses often focus on design.

With this basis, later courses could incorporate group work more effectively. There have always been instructors who have used cases that are analyzed or completed by groups and then presented to the class. While this is unfortunately (and we believe inappropriately) much less common in engineering than in other professional schools, such as business and medicine, it does occur.

More innovative models for group work include brave instructors, who have even ventured into the use of group rather than individual exams. This does not fit the model of individual GPA's, but it is certainly a more realistic model of the group focus of engineering practice.

This leaves us with the very interesting question of looking at how design is conducted. That is the question of analysis and calculation versus historical reference and consulting others. We are not suggesting the traditional emphasis on analysis and calculation can or should be eliminated from the educational process. We do believe that engineers must be capable of this. However, we believe the near exclusive focus on this approach has some pernicious impacts on the practice of engineering.

Because engineers are taught that design should be based on their analysis, even when they find a previous project with a perfectly adequate design that could be reused – they feel compelled to modify that design. This could be offered as a path for incremental improvements, but it is also a major barrier to the development of standardization.

In addition, historical projects are rarely acknowledged as the foundation for future designs, thus the crucial importance of post-project reviews and of a database of designs are not acknowledged. For example, many engineering students are shown the film of the November 7, 1940 collapse of Galloping Gertie, the 2,800 ft. span Tacoma Narrows Suspension Bridge. How many are told of the very similar destruction of: the 255 ft. suspension pier in Brighton in 1836, the 550 span Strait of Menai suspension bridge in 1840, the 1,010 ft span suspension bridge at Wheeling West Virginia in 1854, and the 1260 ft. span Niagara-Clifton suspension bridge in 1889 (Levy and Salvadori). Perhaps engineers could spend less time in communication, if the memories of other engineers were not the only source of organizational knowledge.

Conclusions

These suggestions clearly need better empirical support, before ABET and the CAB can make them requirements for engineering education. However, individual instructors can certainly innovate at the course or program level.

One of our hopes is that other faculty in engineering management will join with us in evaluating what engineers do. There will clearly be implications for engineering, engineering management practice and engineering education.

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