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# IDENTIFYING THE DESIGN ENGINEERING BODY OF KNOWLEDGE

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## Abstract

This paper describes the body of knowledge needed by engineers doing design and it presents a framework to address these needs for technology-based industries. The duality between the factual knowledge-base which engineers acquire through formal university education and the experiential knowledge-base which generally is lacking in most present-day curricula is examined. This duality is paralleled in other professions including law, dentistry and medicine in that each requires the student to acquire a body of analytical and factual information as well as a sense of how to actually practice the profession, a portion of the body of knowledge that we call "know-how". For example, medical students must learn how to give an injection using a hypodermic syringe or create an incision using a scalpel. Young dentists must learn how to drill a tooth and beginning lawyers must learn how to handle the protocol and pressure of a courtroom confrontation. Similarly, for mechanical design engineers to be complete professionals, they must know more than the science and analytical methods that are taught in university programs. They also need an innate feel for machinery, precision measurements and manufacturing methods, as well as a range of professional practice issues. Finally, we describe how we are developing know-how in our Automotive Engineering students at the University of Windsor.

*Keywords: Design Engineering, Education, Curriculum Development*

## 1. Introduction

The global manufacturing industry, including the automotive sector, is undergoing a major shift in operational modes. The new trends include lean production technologies, advanced simulation and virtual testing techniques along with new materials and manufacturing methods such as hydroforming coupled with an emphasis on rapid time-to-market for new products. These trends, and competition from high quality imports from lower cost nations, has created an opportunity and a challenge for Canada's industries [1], [2]. Our manufacturing sector must ensure that it is competitive so that the market continues to select Canadian sources for parts, services and assembly assignments. A source of highly qualified technical people is a key factor in ensuring this competitiveness and this need for the best people has driven a requirement to examine the body of knowledge required by Design Engineers in the future [3], [4].

In Canada, as well as in most other industrialized nations, it is well known that the scientific and analytical body of knowledge is delivered very effectively by university engineering programs. Canadian engineering programs operate under the auspices of the Canadian Engineering Accreditation Board (CEAB) that is administered by the Canadian Council of Professional Engineers (CCPE). The Board includes leading engineers from academe and industry who visit and assess all engineering programs in Canada on a regular basis. The Board (like the ABET in the US) examines all aspects of the program and has recently taken a more pro-active look at issues surrounding design in the curricula, as well as professional practice issues such as communications and ethics.

The University of Windsor is undergoing a major curriculum review including Canada's first university level education in Automotive Engineering. To help inform this curriculum design process we had extensive consultations with industry as well as doing a formal survey to learn their needs with respect to the skills required of mechanical engineering graduates [5], [6].

## 2. The product realization team – past and future

In most manufacturing companies, products are developed by a team, the members of which practice in fairly narrow specialties. The *product engineer* is responsible for the basic conceptual design of the part and managing the overall product realization process, while the *designer* prepares the working drawings and detailing, essentially contributing the geometry of the part. Responsibility for analysis (and therefore detailed compliance with the product specification) is passed to an *analysis specialist* and the manufacturing plan is devised by a *manufacturing engineer*. Figure 1 below shows the general layout of this type of product realization team.

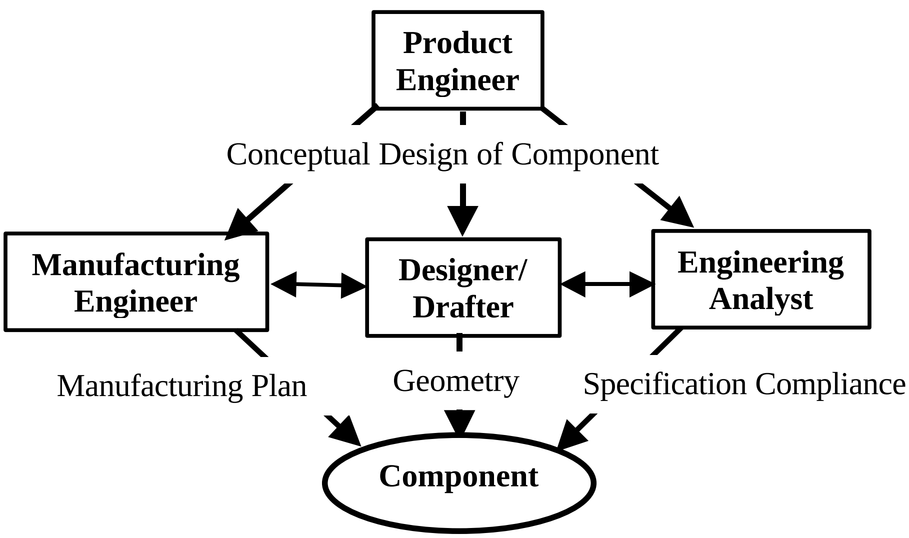


Figure 1. The existing automotive engineering product team – made up of several specialists, each contributing to the development of the physical component [7].

Each of these groups in the technical team has a typical career path and set of prerequisite qualifications for entry. Analysts usually have at least a Bachelor's degree in engineering while many designers have been trained at technical colleges rather than at degree-granting institutions [3]. Their responsibility for performing any engineering calculations (to determine parameters such as stresses, deflections, fluid flow and heat transfer rates etc.) is limited. This system has some distinct disadvantages including: difficulty in managing the work of several people on the same component, too much opportunity for miscommunication and overall higher cost due to the need to provide salaries, benefit packages and physical infrastructure for each person on the product team [3].

The availability of powerful, reliable, easy to use integrated design/analysis packages has made the need to have these separate groups perform tasks such as stress analysis and detailing of drawings much less clear. In the hands of a sufficiently experienced and well-qualified person, the same computer running an integrated software suite can now be used to create the geometry of the part, quickly detail the working drawings and finally, carry out the engineering calculations to ensure compliance with specifications. Thus, it is becoming less cost-effective to have these functions performed by different people in separate parts of the company.

Intense competition has caused each company to ensure that each employee contributes as much value as possible to the product realization process. If the team can be consolidated without compromising quality, performance or delivery, then clearly, only the most capable employees, specifically those capable of performing multiple tasks, will be retained.

## 2.1 The design engineer

One of the key points on this issue is that no amount of sophisticated computer hardware or software can replace engineering judgment or remove the necessity for a critical review of all product characteristics before a production decision is made. The product development team that is emerging combines the roles of designer, analyst and to a certain extent manufacturing engineer, into a highly capable individual known as a Design Engineer [7]. Figure 2 shows this new product realization team and shows the need for an enhanced skill-set in the design engineer.

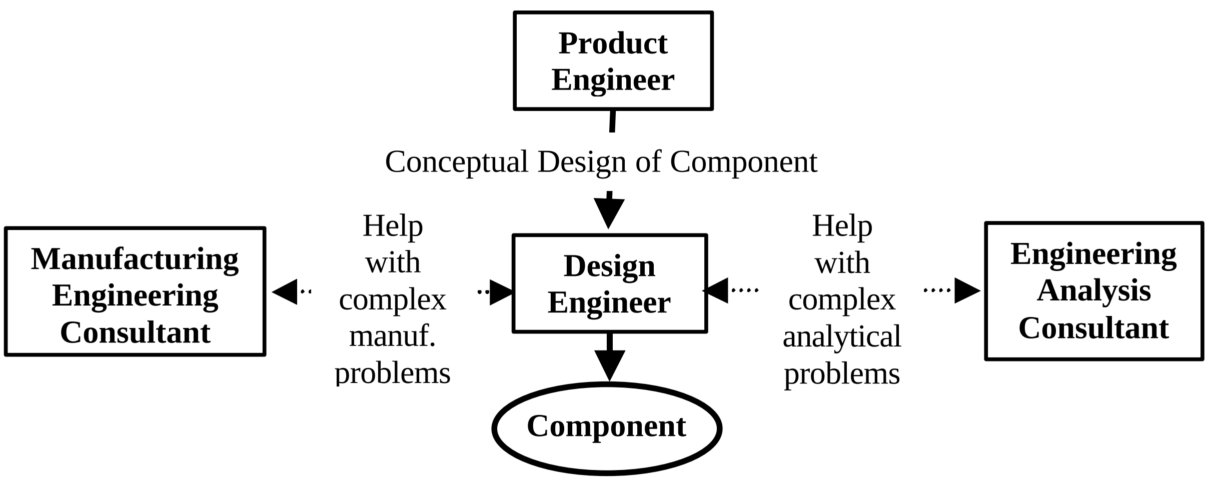


Figure 2. The new product engineering team – the Design Engineer combines several of the previous roles and uses modern design technology to speed the product realization process. Advanced technical specialists are brought-in to assist with complex problems, rather than on routine matters [7].

Due to the need for the Design Engineer to be able to make complex decisions in several fields or subspecialties, the logical educational background to fill this hybrid role is an engineering degree, perhaps with formal post-graduate education but certainly with an on-going program of upgrading and professional development courses to update skills and build new capabilities.

In comparison with the team described above in Figure 1, the Design Engineer combines several roles and calls on senior specialists in a mode that uses them in consultative fashion as they are needed rather than as a matter of routine for every job. The term “consultant” does not necessarily imply an outside consultant. In the case of larger companies, these people are located in-house but usually are only available in sufficient numbers to assist with projects on an occasional or as-needed basis rather than on every project. This results in a more efficient use of staff and a lower overall cost of the product design effort.

# 3. The duality of professional knowledge

The body of knowledge required to practice in any of the so-called “learned” professions such as law, medicine or engineering, is really a duality in that there is a large body of factual information that would-be practitioners must master and another distinct base of practical knowledge that is more difficult to characterize (see Figure 3 below). This second base of knowledge is sometimes referred to in English as “hands-on know-how” and it usually is felt to entail a certain “feel” or set of instincts about the likely consequences of certain choices which every professional faces every day. For lack of a better term we will use the phrase “know-how” in connection with this portion of the body of knowledge.

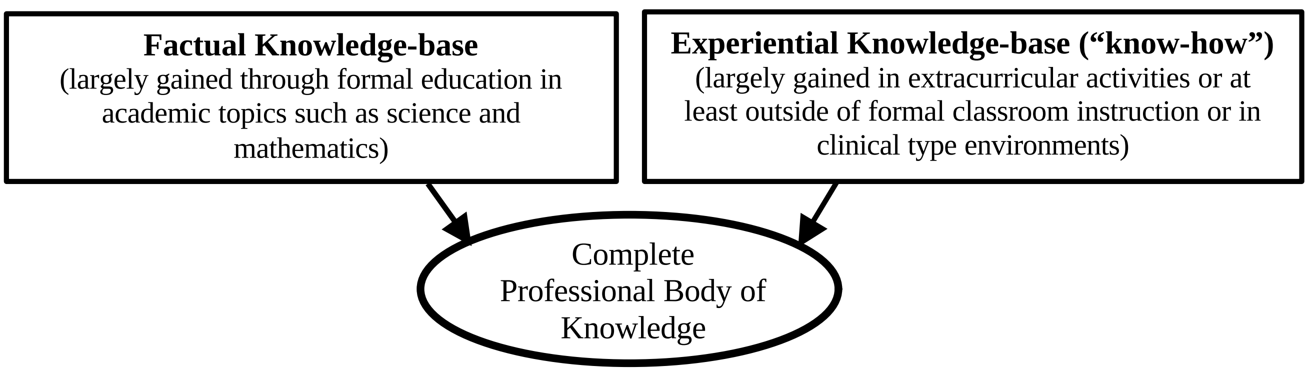


Figure 3. The complete body of knowledge for a professional includes two distinct types of knowledge that are usually acquired in two different modes of education – one involving a great deal of formal classroom instruction and the other less formal and less easy to define, but normally occurring outside of traditional classrooms.

The first body of knowledge (the factual knowledge-base) can be described by a set of key words such as those shown below in Table 1, which compares the medical and mechanical engineering professions. The lists are not intended to be exhaustive, but rather indicative of the parallels between the two professions.

Table 1. Factual Knowledge-Base Keywords for the Learned Professions

| **Medicine** | **Mechanical Engineering** |
|---|---|
| Anatomy | Machine Elements (including analysis) |
| Chemistry and Biochemistry | Chemistry and Physics |
| Physiology | Engineering Science and Analysis (including solid and fluid mechanics and thermodynamics) |
| Mathematics | Mathematics |
| Statistics | Statistics |

Table 1 above shows that both medical students and students of mechanical engineering need a significant grounding in the sciences including physics, chemistry and mathematics as well as certain specialized scientific topics such as anatomy and physiology (for medicine) and machine elements and engineering science analysis for engineering. These topics are all well established in their respective university curricula and surveys (described below) have consistently shown that this knowledge-base is satisfactorily imparted to students.

The other knowledge-base ("know-how") is more difficult to define since it often involves both physical skills and/or a set of judgment skills that are most effectively developed by experience. Table 2 below gives some keywords which describe the types of knowledge that make up this "know-how" knowledge-base. While not exhaustive, it indicates the major elements of the type of practice knowledge that must be acquired by students of the respective professions.

Table 2. "Know-how" Knowledge-Base Keywords for the Learned Professions

| Medicine | Mechanical Engineering |
|---|---|
| dealing with a patient | dealing with a client or coworker |
| performing a physical examination | Assessing a piece of machinery |
| tasks such as measuring blood pressure, administering a hypodermic injection | tasks such as torquing a bolt, installing a seal, aligning a shaft, measuring a small clearance |
| performing even simple surgery | developing a simple design concept |
| interacting with specialists | interacting with consultants |

One key difference between the two professions is that the medical doctor must perform physical tasks of the type outlined above on a daily basis as a regular part of his or her work with patients.

Few engineers perform tasks such as installing seals and aligning shafts on a daily basis but the knowledge of how to actually perform these types of physical tasks is a critical element in knowing how to design products where these tasks must be carried out by others such as technicians and mechanics. Also, for the young engineer to have credibility with these other workers, he or she must have some demonstrable ability to understand and actually do their work and this can only be developed if the engineering student has an opportunity to physically perform these types of tasks personally and repeatedly using real tools and machinery.

## 3.1 Development of the "know-how" knowledge-base

In the case of medical students, the "know-how" knowledge-base is nearly always developed during clinical education as well as in post-graduate residency training experiences which are and always have been, a core element in medical education. Given that the fundamental task of medical doctors is to verbally and physically interact with human patients, the formality and supervision inherent in these types of educational environments is certainly necessary.

Obviously, no-one could condone significant experimentation on humans by untrained people operating without professional supervision and so medical schools are provided with significant staffing and physical resources to ensure that the "know-how" knowledge base is delivered effectively and in a responsible and accountable fashion.

For mechanical engineering students, the process of acquiring this "know-how" knowledge-base has always been quite different. It has often been said that the best mechanical design engineers are those who worked on old cars when they were teenagers or who had the good fortune to grow up on a farm where working with and repairing machinery was an everyday necessity. Thus, the experience used by many engineers to develop this "know-how" knowledge-base was actually acquired before they began their formal education.

The difficulty in present times is that virtually all manufactured products such as modern automobiles, television sets or household appliances are either too complex for any meaningful repairs to be conducted by amateur tinkerers or they are simply so reliable that they hardly ever need to be repaired before their end of life disposal. Thus, the difficulty for most young people today is that they seldom have an opportunity to repair or even closely examine machinery and so they usually arrive at university to study engineering with little or no base of experience on which to build this "know-how" body of knowledge.

In the context of design engineering, this portion of the body of knowledge is fundamental to the development of a good design engineer since it is the critical ingredient that allows the practitioner to apply judgment to the raw results of engineering analysis in making design decisions and choices. These decisions, based on experience and judgment, are the meat of everyday design engineering and the lack of experience results in a missing element of good practical judgment in most new graduates when they are faced with a design task.

This is the problem that modern mechanical engineering design educators face in transforming bright young people into design engineers with well-founded decision making skills. The thesis of the authors is that, in recognition of the need for engineering schools to be able to impart this "know-how" knowledge-base, we need to provide a form of educational environment somewhat akin to the clinical settings used in medical schools to teach these skills to their students. The human and physical resources required to do this will be expensive compared to those needed to simply deliver more classroom lectures but this investment is necessary if we are to properly educate our young people to take on advanced design roles in the future.

# 4. The design engineering body of knowledge

A recent study showed that Canadian industry from a wide array of sectors showed that industry is quite satisfied with the general knowledge-base of new graduates in the areas of scientific and analytical competence [5], [6]. In fact, none of the survey respondents mentioned a problem with the level of basic scientific or analytical skills of new graduates. This study produced results very similar to those found in the earlier PRP study of US industry that was undertaken by the ASME in the mid-1990's [8].

Both studies found however, that new graduates were generally felt to be weak in certain key skills including those associated with design of machinery and knowledge of manufacturing processes. Skill in both creating and reading engineering drawings was also mentioned as a specific need by many respondents. The phrase "hands-on know-how" was used by a number of survey respondents, suggesting that students should be exposed and required to work with their hands on machinery rather than merely studying machinery through the traditional media of textbooks and classroom instruction. In addition, there were certain specialized elements of knowledge that were felt to be important but were generally not dealt with in undergraduate curricula. These specialized topics included:

- Metrology (precision mechanical measurements using instruments such as micrometers, dial indicators, surface roughness gauges and coordinate measuring machines) as well as knowledge of geometric dimensioning and tolerancing (GD&T).
- Design review techniques such as value analysis and design for manufacture and assembly (VA and DFMA respectively).
- Enhanced communications skills and knowledge of the general practices of the engineering business as well as some human relations issues such as teamwork.

## 5. Providing the "know-how" knowledge-base

Providing the "know-how" portion of the body of knowledge is not a simple task because it requires a set of facilities and human resources that universities are not normally accustomed to possessing. At Windsor, we have made a number of major laboratory modifications and hired some key personnel, including a number of younger faculty members along with an experienced technologist all of whom who already possess a strong element of "know-how". Our physical facilities (illustrated below in Figures 4-6 give our program a unique ability to deliver the type of educational experience needed to provide at least the start of the "know-how" knowledge-base.

Figure 4. Mechanical Dissection Lab at Windsor. Students are each assigned a small engine on which they do a complete performance test before dissecting it and making measurements using precision metrology equipment. During the course they learn about all of the manufacturing operations needed to product the components and the visit to the factory so that they understand the scale of operations required to produce even a simple product.

In addition to these facilities and their associated educational programs, we have carefully maintained the scientific rigor which is also crucial to ensuring that our students can utilize all aspects of the knowledge-base and do the advanced work that employment in the modern auto industry entails. The next phase of expansion of these facilities will involve enhanced manufacturing laboratories so that students can learn about all of the major manufacturing processes and modern materials used in producing automobiles as well as many other products.

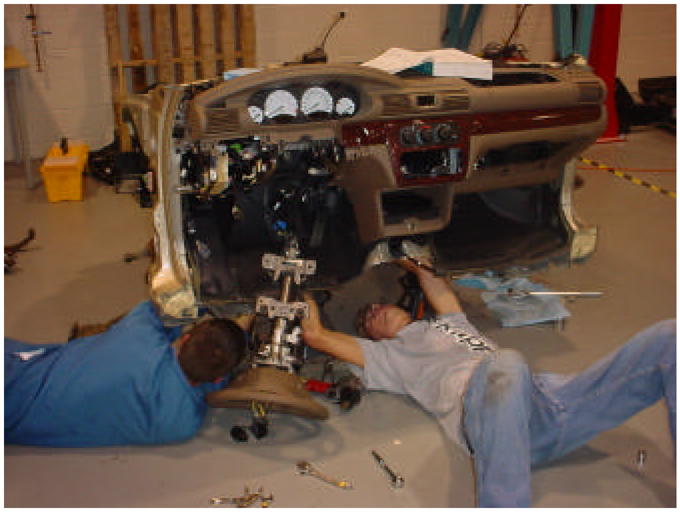

Figure 5. Automotive Engineering Project Room at Windsor. Vehicle manufacturers have provided a number of products which students use for projects. The team above is disassembling the front-end of a 2001 Chrysler Sebring automobile to examine the HVAC systems and front suspension and brake components. The engine and transaxle of the Sebring have already been the subject of another project.

Figure 6. Automotive Engineering Project Room at Windsor. The team depicted above is partially disassembling a 2002 Dodge Dakota pick-up truck to create an operable instructional aid that can be used to examine how modern vehicles are built and how the various parts function together. The vehicle hoist in the background is used to allow students to safely examine various types of vehicles and learn how they are constructed.

## 6. Conclusions

All learned professions (medicine, law and dentistry as well as engineering) require a duality in their respective bodies of knowledge. The two types of knowledge-bases are the factual scientific knowledge of the field and a body of knowledge-base of physical and experiential learning which allows the practitioner to develop judgment and an innate feel for the consequences of choices made in the course of normal practice.

The body of knowledge of the Design Engineer encompasses both factual scientific knowledge of the type usually associated with university education and a different type of knowledge which we refer to as “know-how” that can only be acquired through physical experiences with mechanical engineering products.

In the context of the automotive engineering program at Windsor, we are building a significant capability in both physical and human resources to provide this type of knowledge and we plan to continue to expand this effort as more resources become available.

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