Design Beyond “Doing”

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Abstract

As a relatively new field of inquiry, engineering design is still very much under construction. In terms of its final form, the engineering tradition suggests that engineering design use science to legitimate its knowledge base while emphasising the practical application of that knowledge. To explore this model, agricultural engineering is presented as a case study. Declining enrolments forced agricultural engineering to re-conceive itself, to be transformed from an applications-based (agriculture) discipline to one based on science (biology). Its strong “application” orientation (“doing”) may have contributed to its demise, for it had no well-defined theoretical base (“knowing”) that it could call its own, a nucleus from which it could construct its identity. Engineering design, too, must be careful not to be completely preoccupied with “doing” (creating a product) at the expense of “knowing”. “Knowing” means that knowledge can be an end in itself. Although self-indulgent, “knowing” for its own sake is an essential part of a strong, confident discipline.

1. Introduction

Design has long been a part of engineering. It is only recently, however, that design has been formally brought into the research arena. As a relatively new area, questions arise concerning the legitimacy of certain kinds of research.

If we wish to separate the engineering design research “contenders” from the “pretenders”, it may be helpful to impose some kind of order on the current state of design research. Horvath [1] sees design research as being ordered with respect to purpose. This leads to a sink-channel-source model of design research. Design psychology is an example of source, design science an example of channel and design standardization as design sink.

The source-channel-sink model assumes a movement or flow with all design research eventually accumulating in the sink (akin to a “trickle down” theory). As the sink is the realm of design practice, the model implies a strong value in pragmatism. Love

[2] expresses similar sentiments, seeking to add structure to clarify which “concepts, theories and theoretical strands are pragmatically more useful or better justified” (p. 299). This can perhaps be contrasted with the more abstract thinking embodied in science. Horvath [1] himself sees engineering design as a “partially scientific discipline” (p. 156).

The *scientific content* and the *pragmatic qualities* of a particular branch of design research provide two possible values that can be used to assess its legitimacy. The “application of science” definition of engineering suggests that these two are mutually supportive (“application” alluding to pragmatism) while [1] and [2] hint at possible points of contention. Science, for instance, favours abstractions, whereas pragmatism necessarily requires specific contexts. It is quite possible that it is precisely *because* of the tension that pragmatism and science are mutually supportive in engineering design research, for the former ensures that the research is useful in at least one context and the latter, that the findings are at least partially transferable to another context.

The term “design science” merits closer scrutiny. How should this term be interpreted? One interpretation sees “design science” as an amalgamation of two parts where the “design” of “design science” speaks of pragmatic (“doing”) qualities and the “science” of “design science” speaks of the scientific (“knowing”, from its Latin root) content of engineering design.

Another interpretation sees “design science” as another science, to be reckoned with the likes of physics and chemistry. Here, it would seem, design has at least some “knowing” component. However, it is unclear if the science *facilitates* “design as knowing” or if it actually makes “design as knowing” *possible*. The use of the term “design science” implies the latter, for we do not speak of “physics science” nor “chemistry science”. Hence, it would appear that there exists part of design which falls outside of science, else the term “design science” would be redundant. This further implies that design enters the “knowing” realm exclusively, or at least ideally, in the presence of science.

If we wish to posit “design as knowing” in its own right, we need to partially divorce our concept of design from practice. In addition, the “knowing” part of design is no longer assumed to be dependent on the “knowing” qualities of science. In other words, research in engineering design is conducted not just because it leads to better design, but because it allows us to know and understand our world in ways that would be difficult or impossible without it.

In drawing attention to “design as knowing”, we need to distinguish between different kinds of knowing. The “rise of rationalism”, at the time of Descartes, shows a shift in “knowing” values. In the 16th century, considerable intellectual value was placed on knowledge of the oral, the particular, the local and the timely. Early in the 17th century, these values shifted, and knowledge based on the written, the universal, the general and the timeless came to dominate [3]. The high value placed on abstract ways of knowing has continued to this day and it is this form of knowing to which I refer when I speak of “design as knowing”.

We must be careful not to let the “knowing” slide back to the “doing”. Within engineering design, we can analyze a beam and determine its deflection under load by resorting to science (*i.e.*, “strength of materials”). Abstraction refers to the fact that we can apply these theories whether the beam is part of a bridge, a building or a conveyor system. Knowing, in this case, is seen as instrumental to the doing (knowing *with* doing). Of greater concern here is knowing *without* doing. Consider Einstein's “ $e=mc^2$ ”. As an engineer, I am very much expected to *know* this. However, there is no expectation that I should ever *do* anything with it. And indeed I have not.

2. Objective

My objective is to show how the concept of design as a way of “doing” with little regard for “design as knowing” (*sans* “doing”) risks relegating design to second class engineering research and jeopardizing its future.

3. Approach

To demonstrate the importance of “design as knowing”, I will use a simple case study approach, examining the circumstances surrounding the naming and curricular changes of “agricultural engineering”. I will then draw on my own experience where I moved from agricultural to mechanical engineering, while simultaneously changing my orientation from an analytical to a more interpretive approach.

4. Case Study: Agricultural Engineering

During the 1980s, student enrolment in departments of agricultural engineering in the U.S. and Canada was dropping [4]. Interest in agriculture appeared to be on the decline. If the discipline, or some form of it, was to survive, some changes needed to be made. This began largely with a name change – “agricultural” was out and some form of “bio”, (*e.g.*, “biological”, “bioresource”) engineering”.

4.1 Applications-Based vs Science-Based

Although a name change may seem rather simple, it is actually quite a complicated affair. The change draws attention to the fact that not all engineering disciplines are constructed or categorized according to the same reference point. Some fields of engineering can be called applications-based, while others are better described as being science-based [4].

Agricultural engineering is applications-based, concerned with agricultural production. Engineers working within this economic sector may apply a broad range of engineering theory, depending on the particular problem at hand. Other applications-based engineering disciplines include mining, power, petroleum and ceramics engineering [4]. To this list, we might add military and environmental engineering, and perhaps manufacturing as well.

Early science-based disciplines include mechanical and electrical engineering, based on the science of physics, and chemical engineering, based on the science of chemistry. Biological engineering is a more recent addition, and we might add materials engineering as well, although “materials science” would not appear to be on Johnson's [4] list of “foundational” (p. 3) sciences. Science-based engineering disciplines are so called as they generally focus on a particular branch of science which, in turn, identifies the kinds of engineering problems they are likely to address.

Civil engineering presents an interesting taxonomic challenge. As an alternative to military engineering, “civil” engineering seem more applications-based. Civil society is, however, perhaps too nondescript to be a meaningful sector of application. Others view civil engineering as science based [5]. If we consider civil engineering to include the design and construction of buildings, bridges, highways and waste treatment plants, the theoretical base is rather too dispersed to merit the designation “science-based”. I will leave it as “unclassified”.

The idea that engineering be based on science can probably be traced back to Pierre-Simon Laplace, a French mathematician, who, in the first half of the 19th Century, took control of the prestigious *Ecole*

Polytechnique from Gaspard Monge [6]. Monge favoured practical applications and saw laboratory work as an essential part of an engineering education. Laplace, however, valued the theoretical and all but eliminated the laboratories. He wished to turn his engineers into scientists.

The transformation of agricultural engineering into “biological engineering” would appear to be following this historical trend. However, the relatively recent rise of “environmental engineering” would deny that such a trend is universal. Perhaps the transformation was necessary because the term “agricultural” no longer adequately described the current concerns of the discipline. The persistence of the name “civil engineering” shows this reasoning, too, to be questionable.

A more plausible reason for the transformation is the falling out of the term “agriculture” from the political limelight. Only those re-named agricultural engineering departments which completely removed the word “agricultural” saw a significant increase in student enrolment [7]. Scott [5], working in the Department of Biological and Environmental Engineering, with its “roots in agricultural engineering” (p. 11), discusses the possible curricula for “biological engineering”. Neither “agriculture” nor any of its derivatives appear in any of the titles or descriptions of the courses he proposes. The same trend can be seen outside of engineering. In 2005, the “Faculty of Agricultural Sciences” at the University of British Columbia became the “Faculty of Land and Food Systems” [8].

As “agriculture” fell into disfavour, so did “agricultural engineering”. The studying of agriculture was no longer in fashion; it would seem that all the major problems had been “solved” and there were not enough challenges available for new minds. “Agriculture” had become *ordinary*.

The transformation of agricultural engineering to an engineering based on science brings two issues to light related to research in engineering design. First, it demonstrates that certain terminology may suffer from a loss of status as it slowly becomes “ordinary”. How then, might we prevent engineering design from being viewed as “ordinary”? Second, the transformation draws attention to the applications- and science-based distinction with regards to the “types” of engineering. To what degree, therefore, might research in engineering design depend on the “type” of one’s engineering background? I shall address the second question through my own personal experience and provide possible answers to the first question.

4.2 Agricultural Engineering Meets Mechanical Engineering

My own career began in agricultural engineering, where I worked in post-harvest treatments. I entered mechanical engineering with my Ph.D. program. As a newly arrived graduate student about to embark on doctoral research, I was offered to work in the area of engineering design. It seems that I was one of the few students who had “practical” design experience, albeit in agricultural, not mechanical, engineering, and I was therefore seen as a good candidate for the research. The idea of *research* in engineering design, however, was completely new to me.

After considerable effort, I found my research niche and I and the other graduate students were asked to present our research to the department. I decided to present what I considered to be my most original piece of work. Some faculty members were intrigued with my work, others objected, believing my work best be done elsewhere, if at all.

I spoke at length to one of the faculty members who had objected. I found the conversation confusing, for it seemed that we were operating on two different wavelengths. Enough signals were coming through, however, that I was getting this uneasy feeling that I had violated some sacred rule of mechanical engineering. But I had no idea what it was.

In my mind, I *had* fulfilled “the” sacred rule of engineering, namely, that of *utility*. I had my practical design experience; I had done extensive research and I had concluded that this work needed to be done, for it was something I wish I had known when I was doing design during my pre-doctoral days. It didn’t seem to matter, however, that I had passed the “utility” test, there seemed to be another test that I hadn’t passed, and this test clearly took precedent.

I suspected that my inability to spot my misstep was related to the fact that I had a background in agricultural engineering rather than mechanical engineering. After extensive reflection, I have concluded that there are at least two pre-utility tests that must be passed:

- 1) *Is your research science-based?*
- 2) *Does your research honour and promote the discipline (e.g., mechanical engineering)?*

The first point assumes that any research in engineering design must echo the science upon which the particular field of engineering is built. As I explored design in the presentation which sparked the original conversation, I had indeed stepped outside of science. Based on my experience as an agricultural engineer, I saw stepping outside of both engineering

and science as normal. My undergraduate program, for example, required that I take courses in plant science, animal science and soil science, all fields of study in their own right. The department I studied in was in the faculty of agriculture, but the (professional) degree was granted by the faculty of engineering. As a research engineer in the area of plant quarantine, I worked on a multidisciplinary team. My experience had told me that engineering concepts alone are often insufficient to complete an engineering project in a field as broad as agriculture. I saw engineering design as being equally broad for design, like agriculture, extends beyond engineering.

The second test speaks of one of the goals of engineering. As an engineer working in agriculture, the goal was quite clear to me, namely, the improvement of agricultural production. In science-based disciplines like mechanical engineering, the goal has no direct equivalent and must be stated differently. The second test assumes that that *one of the goals of mechanical engineering is mechanical engineering*.

In agricultural engineering, the problems are derived from agriculture. The solutions are returned, essentially in full, to agriculture, from whence new problems arise, and the cycle continues. In mechanical engineering, the second test implies that once a solution is developed, only *part* of the solution is returned to the “real world”; some is deliberately withheld.

These two “tests” highlight the differences between applications-based and science-based forms of engineering. Applications-based engineering disciplines have a relatively well-defined goal (e.g., agriculture). The goal is understood in terms of a broadly based sector, which speaks of a community of people of varying backgrounds working together to a common end. Applications-based engineering is therefore predisposed to multidisciplinary approaches to problem-solving. The well-defined goal and broad domain, on the other hand, leads to an *ill*-defined theoretical base. Any area of study, including but not limited to science, is a possible candidate and these are constantly reassessed as one moves from one project to the next. Practice is valued over theory and solutions are therefore, to a large extent, problem-based. Hence, engineers often look to the larger community of practice for recognition and approval.

Science-based engineering types lack well defined domains of application. There is no distinguishable outside community to which engineers might readily belong. Mechanical engineers, for instance, can design products for use in agriculture, mining or the military. The dispersed communities make it difficult to identify an over-arching goal. In sharp contrast,

science-based disciplines do, by definition, have fairly well-defined central theories, typically some branch of physics (e.g., mechanics, electricity). The favoured theory dictates which kinds of engineering problems are likely to be addressed. Consequently, science-based disciplines do not invite multidisciplinary approaches for to attempt problems that go beyond the theory is a step away from the discipline, potentially calling the discipline itself into question. To promote the discipline, one must necessarily promote the theory upon which the discipline is based. The extent to which a given solution upholds the central theory is a strong measure of the success of the solution.

The upholding of the theory has some far-reaching consequences. From an applications-based perspective, this “recycling” of the solution within the discipline itself is rather wasteful and blatantly violates the “utility” test. In fact, the recycling is downright self-indulgent.

Self-indulgence is, however, not without its utility, for if engineering is to “serve the public”, it must necessarily serve itself. By maintaining a central theory, engineers receive part of their recognition and approval from within and are not completely subservient to outside forces. This provides a kind of steadying keel, creating a relatively stable tradition and leads to a strong sense of identity.

4.3 What Went Wrong

Agricultural engineering's preoccupation with practice would appear, at first glance, to be a noble calling, promoting the value of utility. The success of the engineering is measured by the success in the field which means that as much engineering as possible must end up in the application. There is very little left over that the practitioners can call their own and their sense of identity is diluted within the larger field of agriculture. This dilution makes it difficult to create an central core, for this would require some theory or iconic entity that speaks of both agriculture *and* engineering. Lacking such a banner to look back upon to remind themselves of who they were, agricultural engineers were unable to develop a strong sense of identity. This void is projected to the external community and agricultural engineering became insipid, viewed from the outside as “ordinary”. Agricultural engineers had promoted utility at the expense of identity.

5. Implications for Design

As an engineering discipline, what can engineering design learn from the struggles of agricultural engineering? What steps should be taken or avoided to ensure that engineering design is a discipline in its

own right with a promising future?

5.1 Applications- or Science-based

Tradition dictates that engineering disciplines be either applications-based or science-based. Which is more appropriate for engineering design?

Applications-based engineering, with its preoccupation with practice, is an appealing choice for engineering design, for so much of design is connected to “doing”. It is difficult, however, to identify a community of practitioners, such as in agriculture, to which engineering design can belong to outside of itself. Like “civil”, “design” is too vague. Furthermore, the term “engineering design” is problematic, for tradition suggests that the term be “design engineering”. This points to a misfit, for if “engineering design” is an intelligible term, then we would expect “engineering agriculture” to be equally meaningful. Such is not the case.

The science-based discipline would presumably be the preferred choice of those promoting design science. Which science should engineering design be based upon? The “big three” seem to be physics, chemistry and, more recently, biology. The *mechanical* qualities of many engineering components used in design suggests physics as the obvious choice, whereas the fact that these components have *functions* suggests that biology would be better. If we are more concerned with the design process, then chemistry may be the appropriate base. With so many sciences as potential candidates, engineering design is beginning to look more applications-based with a dispersed theoretical base.

As a science-based engineering discipline, engineering design may require a *new* science. The creation of a new science constitutes a major departure from engineering tradition on several fronts. First, engineers are more used to borrowing the sciences of others than developing their own. Second, the “foundational” sciences which are seen to form the bases of the more traditional engineering disciplines are all derived from observing nature. The new science must deal with the creation of that which does not yet exist. This brings us, of course, to Simon's idea of the “sciences of the artificial” [9]. Unfortunately, Simon uses mathematics as a model for design and the shift from the closed solution (puzzle solving) of mathematics to the open solution (problem solving) of design is not adequately addressed. Finally, the traditional engineering disciplines are *science-based* but are themselves not sciences. The sciences that form the bases are all fields that exist quite independently of engineering. If design science is the science upon which engineering design is based,

and this science occurs *only* in engineering then, unlike the traditional disciplines, it becomes very difficult to distinguish the science from the engineering.

5.2 Theoretical Base

Even if not science-based, the *idea* alone suggests that engineering design have a recognizable, theoretical core. Recognizability implies that when people think of engineering design, they think of this theoretical core, and when the theory is mentioned, engineering design immediately comes to mind.

Recognizability affects engineering design on a number of fronts. Funding agencies must be convinced that those conducting research in engineering design are in possession of knowledge not readily accessible to those in more traditional engineering fields. Prospective students contemplating a career in engineering need to understand how “engineering design” relates to a career. Those in industry seeking to hire engineering graduates need to know what “engineering design” can offer beyond the more traditional approaches. Each of these groups will ask the question, “What is engineering design?” The discernible theoretical base will answer that question in ways that a series of designed products never can.

A strong theoretical base means that those working in engineering design will have something beyond practice to uphold. Upholding the theory means that part of each (research) project is re-directed to reinforce this core, providing a stabilizing effect on engineering design. Outside forces do have an effect, but this effect is tempered by the theoretical base.

A strong central theory implies a loss of utility. This loss, however, is really a loss of *external* utility, for it does provide significant *internal* utility by reason of the stability created. This may be interpreted as offering indirect external utility in that outsiders are more likely to trust a discipline perceived to be stable.

The witting loss of utility demands that engineering design be self-indulgent. In other words, one of the goals of engineering design must necessarily be engineering design. An important benefit of self-indulgence is the creation of a strong sense of identity. To say that one is working in engineering design is to say that one *is* somebody.

The theoretical core necessarily means that design can longer be viewed as only “doing”. Design must also be viewed as “knowing”. This “knowing” is not knowing so that one might “do” better. Self-indulgence demands that this “knowing” be “knowing” for its own sake; “knowing” is its own reward.

5.3 Pitfalls

Engineering design must be careful to avoid the pitfalls of a strong theoretical base. If this base grows too strong, engineering design will become impervious to outside influence and no longer properly serve the needs of its clients. Excessive reliance on a theoretical base leads to viewing other theoretical leanings with suspicion. Solutions that wander too far from the theoretical base are reined in to maintain alignment with that base, risking misalignment with the original problem. Multidisciplinary approaches are also discouraged, and this could quickly compromise a field as varied as engineering design.

Multidisciplinarity is perhaps the greatest challenge to creating a strong, recognizable theoretical base. As the number of included disciplines increases within a multidisciplinary framework, theory diversifies and recognizability suffers. Narrower theoretical bases tend to lead to greater recognizability. The task, therefore, is to create a recognizable over-arching theory that allows for diverse (sub) theories to comfortably co-exist.

6. Conclusion

As a relatively new discipline, engineering design needs to carefully consider the directions its research will take. The discipline must be recognizable to students, industry leaders and funding agents. It must therefore bear some resemblance to the more traditional engineering fields, yet distinct enough to have something unique to offer.

Much can be learned from agricultural engineering. Declining enrolments forced departments to reconsider the traditional areas of study. Many of these departments reconstructed themselves as a form of “biological” or some “bio” type of engineering. The name change was intended to reflect some changes in research directions, but at the same time shifted the discipline from an applications-based engineering to one based on science.

The rise in student enrolment indicated that an engineering field with an identifiable theoretical base provided by science was more attractive than one of an ill-defined base typical of applications-based fields. Further comparisons with mechanical engineering suggest that an ill-defined theoretical base leads to a weak sense of identity for there is no reservoir where ideas can be deposited and withdrawn (recycled) and confirm what one is all about.

Engineering design must develop a strong theoretical base. This base must be recognizable from within and without, and present engineering design as

a contender with characteristics that distinguish it from both other engineering and other design fields. The theoretical base must be narrow enough to afford recognizability and broad enough to support multidisciplinary.

The theoretical base demands that engineering design be viewed not only as a way of “doing”, but also as a way of “knowing” and part of this “knowing” must be detached from “doing”. This theoretical base must speak specifically of engineering design.

As unique to engineering design, the theoretical base provides a beacon and a refuge, a constant reminder of who one is, a place from which to build one's identity. In order to uphold this base, one must be, at times, self-indulgent. This means that part of engineering design is done just for engineering design, without regard to some utility to some outside client. This will help create a strong, confident discipline. And engineering design will be, at least in part, its own master.

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