Development and Testing of Hypotheses in Engineering Design Research*

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Engineering Design Research (EDR) has yet to be fully established as a legitimate field of inquiry. Design Researchers don't often cast their efforts into the scientific paradigm of *hypothesis* creation and testing, resulting in the present situation where analysts and Scientists find little justification for EDR. The apparent lack of scholarly or intellectual content appears to be related to a number of factors:

- Rigor and scholarship in the technical arena have become associated with skillful analysis.
- Engineering design is a creative endeavor, and at least partially falls outside the world of analysis.
- Objective evaluation of engineering design work can be difficult.
- Understanding of the process by which designs are synthesized is poor.
- EDR often lacks a clear hypothesis and testing method.
- Differentiation between design work done in industry and EDR can be difficult. Not all design is legitimate EDR.

It is design, or the synthesis of useful devices, which distinguishes engineering from science. In fact *design* is the very essence of engineering.

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Webster defines *engineer* as:

> One who designs or contrives; an inventor.[1]

Webster also defines *engineering* as:

> The application of science and mathematics by which the properties of matter and the sources of energy in nature are made useful to people in structures, machines, products, systems, and processes.[2]
>
> . . . Chief among (the contemporary engineering designations) are: Mechanical Engineering, applying to the designing, construction, and use of apparatus that generates, transmits, and uses power.[3]

To be a good engineer, one must both be fluent in the use of relevant analytical and experimental tools, and adept at synthesizing or creating solutions to problems. However, the integration of design and analysis is not widely taught, and the quality of engineering design in the U.S. has suffered. Our current trade deficit is one important indicator of this effect.

Recently there has been an effort within the country's best engineering schools to correct this weakness by placing a strong emphasis on educating engineers in the methodology of design (as well as conducting research in engineering design). These schools have sizable Mechanical Engineering faculties, of whom approximately one-third are in the mechanical systems and engineering design disciplines. The importance of this effort was recently illustrated when both the National Science Foundation and the American Society of Mechanical Engineers produced documents supporting university activities in engineering design and altered their policies in favor of greater support for instruction and research in this area.[4] A substantial level of federal funding for engineering design research now exists within several new programs. Despite all of this, research in engineering design still seems to lack validity.

A significant problem with EDR that contributes to these difficulties, is poor hypothesis generation and testing by researchers in the field. For example: it is

[1] Webster's New International Dictionary of the English Language, 2nd Edition, Unabridged, 1942, G. and C. Merriam Company, Publishers.

[2] Webster's Ninth New Collegiate Dictionary, 1984, Merriam Webster, Inc.

[3] Webster's New International Dictionary of the English Language, 2nd Edition, Unabridged, 1942, G. and C. Merriam Company, Publishers.

[4] Reid, K.N. *et.al.*, *Research Needs in Mechanical Systems; Report of the Select Panel on Research Goals and Priorities in Mechanical Systems.* New York: ASME (Sponsored by the NSF), March, 1984.

Rabins, M.J. *et.al.*, *Goals and Priorities for Research in Engineering Design*. New York: ASME (Sponsored by the NSF), July, 1986.

not valid to simply hypothesize that a device to perform a certain function can be designed and fabricated. This "hypothesis" naturally begs the question: "Why?" and as such is not a legitimate focus for research.
A hypothesis of more genuine nature might be:

> A certain device will perform a function better than all other devices, or: a certain device will help to discover some underlying aspect of something.

These hypotheses lack the clarity of more the more traditional scientific disciplines, and indicate the poor mapping of the scientific paradigm onto EDR. They may more properly appear to be research into the "something", that incidentally required the development of a special device to perform.

To develop the field of EDR from its present infancy will require investigation into aids for the process. An example hypothesis might be:

> A particular aid to the design process will help engineers perform design more rapidly, with higher success rates, or to create better designs, and (perhaps) may expose some underlying structure of the design process itself.

Given that a valid technique for testing such a hypothesis is developed, this quite clearly falls into the scientific paradigm. An example from a successful research program into one particular type of engineering design took the following path:

1. Propose/hypothesize that a set of rules for design can elucidate part of the design process.
2. Develop those rules.
3. Have novice designers learn the rules and apply them.
4. Measure their design productivity.
5. Evaluate the results to confirm or refute the hypothesis.
6. Refine the hypothesis.

Another example hypothesis might be:

> A robotic terminal device (hand) can be designed an fabricated that will mimic the natural hand with sufficient fidelity to permit exploration of strategies to orchestrate its use. This can lead to an understanding of grasping and fine manipulation both for robotic applications, and also for biological systems (natural human hands).

The testing of this hypothesis requires the design and development of a series of hands, but nonetheless is characteristic of good EDR work in that it clarifies the purpose and direction of the research (and indicates that EDR need not only be research in the design process itself).

Even science and analysis don't often proceed along the idealized path of: hypothesis creation, test creation, test execution, results evaluation, hypothesis refinement, etc. A hypothesis is often only reached after a great deal of exploratory research has been performed in the field. Neither Watson nor Crick *started* with the hypothesis that DNA has a doubly helical structure of patterns of interconnecting nucleic acids. Rather they hypothesized that a discoverable structure did exist, and only after much work did they suggest and test any particular structure. Almost all research proceeds in this fashion (it is, however, reported as if it were conducted by starting with the hypothesis). This situation is defensible. A valid hypothesis and test are required to validate the results of research, and to place its worth in proper perspective. The fact that the hypothesis was only reached after the research was quite mature need not reduce the validity, nor the worth of the work.

Engineering design research *is* more than the creation of new designs. Designing a new toaster probably by itself is not EDR. The format and structure of inquiry must clearly differentiate it from day-to-day design work done in industry. This is where hypothesis creation and testing plays a central role, despite the poor match of the scientific method to EDR. It provides a vehicle for focusing the research, and substantiating the results. The examples enumerated above indicate that design research can (with care) be placed into the scientific paradigm, and it is quite evident that the development and testing of hypotheses in EDR will help to clarify the intellectual and scholarly content of the field, and answer the questions of legitimacy.

References

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3. Price, K., “I’ve Seen your Demo; So What?” Proceedings of the Third Workshop on Computer Vision: Representation and Control, IEEE Computer Society, October, 1985, pages 122-124.