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Introduction to engineering research

1.1 Why engineering research?

The disciplines of engineering are all described as the application of science to realistic systems which benefit humankind [1]. Engineering research is therefore based on the principles of scientific research which, in turn, are based on the scientific method, in which observations (experiments), theories, calculations and models are derived from the existing body of scientific knowledge and verified independently by others who are experts in the field [2–4]. This latter process is called ‘peer review’. While this formal review by peers is not foolproof, it constitutes the best method of validation and verification of research results. Engineering research is based on precisely the same scientific method; however, the research is directed toward the practical application of science to products, services and infrastructure.

Most research starts with a hypothesis; that is, a statement which can be either proved or disproved. In most cases it is easier to disprove a hypothesis because only one counter example is required to discredit the idea. To prove a hypothesis, it is necessary to exhaustively examine every possible case and make sure the hypothesis applies. Often this results in the creation of limiting conditions. The conclusion becomes slightly modified in that the hypothesis is valid providing certain conditions are met. A full evaluation of a hypothesis may take many years without a conclusive resolution.

Example 1.1 **Hypothesis statements**

'All mechanical systems can be described by damped simple harmonic motion equations.' You could test many mechanical systems and find that this is true. However, if you find one example where this is not true, then the hypothesis fails. In this case, it is necessary to apply some limits to the statement.

'The maximum efficiency of a solar cell is 28%.' If you find one example of a solar cell which has a higher efficiency, then the hypothesis fails.

'The laws of physics apply throughout the universe.' Physicists and astronomers continue to assume this is true when describing the formation of stars.

The history and philosophy of science encapsulates the scientific method and the creation of new knowledge [2–4] based on a new theory which has been subsequently verified by observation, experimentation and the logical development from previously accepted theories, but this is not the subject of this book. In some cases theoretical concepts are deduced long before experimental verification. In other cases, theoretical concepts are deduced from experimental observations. The history of science is full of examples of both.

There are many books which discuss scientific research and its methods [5–8]: so how does engineering research differ from research in science? A preliminary answer is to require engineering research activities to fulfill all of the following objectives:

- The research must be applied to human systems;
- The research must yield practical outcomes;
- The research must yield outcomes which benefit humanity;
- The research must be ethically based;
- The research should consider environmental outcomes;
- The research must be based on standard industry based testing.

A more detailed explanation of these issues is provided in the following chapters.

Example 1.2 **Research opportunities**

A new material has been proved scientifically to be a reliable replacement for asphalt and concrete for road building. The material has excellent physical and chemical properties. An engineering research study of this material might also verify that the material is in abundant supply from renewable resources, the material itself can be recycled at the end of its usefulness in road material, and the toxicity of the material does not adversely impact the environment.

A new transistor technology is based on a rare-earth metal which has extremely low abundance, is difficult to obtain and difficult to recover from e-waste. The research in this field constitutes esoteric science rather than engineering research because the outcomes are unlikely to be adopted widely unless improved environmental outcomes can be assured.

Air transport using hydrogen balloons requires very little energy to raise the load and return the load to the ground. It was found to be not practical because of the flammability of the gas, its confinement/storage is difficult and the speed of movement is highly limited.

Clearly scientific research and engineering research are not mutually exclusive. All medical science is directly related to improving the human condition through medical practice. Other human related fields, for example physiology, pharmacy, dentistry, psychology, education, etc also have some outcomes relevant to improving the human condition. Similarly many engineers engage in purely scientific research to test ideas with the long term aim of finding solutions to the practical implementation problems associated with the research outcomes. As there is no clear dividing line between these fields, many conferences and scientific journals report both scientific and engineering based research. This book is confined to engineering based research strategies, but the concepts are also very applicable to purely scientific research. Thus, further reading is readily available from scientific research methods books and papers [7–9].

Engineers, and hence engineering research, are constrained by quite formal codes of ethics. Every discipline of engineering has a code of ethics covering engineering practice in one or more different countries. The codes should influence how the research is conducted and ensure that the outcomes are improvements to humankind through improved environmental outcomes and minimal risk to users of the technology. In particular the concept of economical engineering design must be balanced with aspects of fail-safe and an understanding of materials and product reliability. In many cases these aspects are inherent in the research design, but good engineering research outcomes will require independent verification of not only the research itself, but also the applicability of systems designed from these research outcomes. Codes of ethics and their importance are discussed in Section 1.4.

A research project is not complete until the results have been presented publicly for other experts in the field to comment and review. Thus publication of findings in the open, refereed, international literature and/or presentation at a meeting of research peers is an essential requirement of any research project. Only when the research outcomes have been reviewed by suitably qualified peers can the researchers declare that new knowledge has been created. This means that work conducted in secret (for example in a military research facility, in a high security research laboratory, or in other private venues), does not contribute to the world-wide body of knowledge, and therefore cannot be described as research.

Example 1.3 **Unsubstantiated claims**

Claims that top secret research by the US Government had revealed the existence of unidentified flying objects and the landing of extraterrestrial creatures have never been subjected to international scrutiny and so must not be regarded as contributing to new knowledge.

Some claims of aromatherapists, chiropractors, water diviners, etc have never been substantiated by rigorous scientific examination and so do not contribute to new scientific or engineering knowledge.

Similarly, a search of previous publications and patents does not constitute research. Thus, when a primary school child conducts 'research' on the Great Wall of China by copying the outcomes located using a computer search engine, this does not constitute rigorous scientific or engineering research. This student is gathering well established and previously reported information. This is an important distinction: research outcomes which are new to the researcher but are well known to others does not constitute original, publishable research. As a logical consequence of this argument, any original research must clearly identify all relevant prior work before the authors can claim to have developed new knowledge. This can be a significant challenge as the volume of published works continues to grow at an accelerating rate.

1.2 Next step research

All research is built on the background and understanding of science developed over the centuries. When a person plans to engage in a research project to create new knowledge, it is vital that a recent and thorough understanding of the field is gained before designing the research project. A new research project will be built on the work of others, from Newton and Maxwell to Mohr and Edison. In addition, the research strategy and methods applied should be well regarded by the world-wide community of scholars.

In order to emphasise this concept, it is possible to describe two approaches to research: (a) A new fundamental innovation that changes the way we think about the world in scientific terms. This can be described as a paradigm shift. (b) A step forward in our understanding of the engineering world based on one or more of the following ideas:

- The application of techniques commonly used in one field to another field;
- The modification of an existing concept or technique with improved outcomes;
- The modification of current technologies for improved efficiency, miniaturization, sustainability or environmental outcomes.

Example 1.4 **Translational research opportunities**

Mechanical engineers used the finite element method for many years before the electromagnetic equations were solved numerically using the method. This resulted in a new field of computational electromagnetics in the 1980s.

Image analysis techniques used for face recognition and satellite based vegetation categorization can be applied to two and three-dimensional data sets in any field of engineering.

Inertial sensors used in the automotive industry as air-bag triggering devices are now used in sports engineering for movement analysis and in mechanical engineering for vibration analysis.

1.3 Research questions

A common method of focusing on a research project is to phrase a research question. The design of a single, succinct question is a challenge for all researchers and the research team may consider several iterations before it is accepted. The research question will directly lead to one or more methods of investigation, and these can be divided into a number of research aims.

The research question can be phrased using one of the following questioning words:

Why?

Example 1.5 Research question 'why?'

Why did the wind turbine fail in 100 kph winds?

This question suggests a number of avenues of investigation. For example the researchers might:

- review the literature for previous failure reports,
- assess the wind conditions at the time of failure,
- undertake numerical modelling experiments,
- review fatigue and possible points of weakness,
- conduct inspections of other wind turbines located in the area.

What?

Example 1.6 **Research question 'what?'**

What is the effect on the strength of concrete when recycled concrete is used in the mix?

This question suggests a number of avenues of investigation. For example the researchers might:

- review the literature seeking results from previous trials,
- conduct compression and shear experiments using different mixtures of concrete,
- conduct strength calculations based on aggregate strength theory.

How?

Example 1.7 **Research question 'how?'**

How can the braking system of a railway carriage be self-activating when its velocity exceeds a threshold value?

This question suggests a number of avenues of investigation. For example the researchers might:

- review the literature and patents for automatic braking systems,
- calculate the braking power required,
- conduct model-based experiments on braking systems.

When?

Example 1.8 **Research question 'when?'**

When will the roof bolts in an underground tunnel fail through environmental degradation?