Responsible Conduction of Engineering (RCE)

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Responsible conduct of research (RCR) classes, web tutorials, conferences, and seminars are becoming common across universities in the United States. Materials for these programs are focused predominately on graduate students and post-doctoral trainees with typically limited involvement of research faculty. For undergraduate engineering students, ABET accreditation requirements mandate material on engineering ethics be presented. These presentations to undergraduates range from classes in ethics given by the Philosophy department to "Engineering across the curriculum" programs embedding ethics exercises into traditional engineering courses. These two levels presentations of responsible conduct are quite different with RCR courses focused almost exclusively on hypothesis-driven, experimental research and undergraduate engineering ethics courses focused on professional practice and engineering design with little or no coverage of experimental research.

For graduate students in engineering, there is the assumption that RCR programs developed for science students will apply with little modification. However, the experience of engineering graduate students, both in the laboratory and after graduation, is likely to be quite different from the student in the sciences. These students may perform hypothesis-driven, experimental research projects like science students but are also likely to work in engineering design, forensic analysis and/or engineering modeling. Their job prospects after graduation are as likely to be industry as academia. It is, therefore, important to consider the unique needs of instruction in both responsible conduct of research and responsible conduct of engineering when creating RCE programs for graduate students and post-doctoral trainees in engineering. To examine what a course in RCE should contain, we can look at several parts:

Responsible Conduct of Hypothesis-Driven Research

For the RCR component of RCE programs, the topics are similar to those presented to science students and resources such as "On Being A Scientist"[1] are useful. These topics include:

- Data Integrity and Appropriate Reporting of Statistical Methods
- Conflicts of Interest
- Publication and Openness
- Allocation of Credit
- Authorship Practices

- Confidentiality
- Falsification, Plagiarism, Fabrication
- Mentorship
- Human/Animal Subjects

The coverage of this topic may vary between engineering disciplines (for example Bioengineering students are more likely to need coverage of human/animal subjects).

Responsible Conduct in Engineering Design

Unlike scientific research, where the goals of the work is to prove or disprove a hypothesis in order to increase understanding, engineering design is a process of examining a set of problems and using principles of science and mathematics to come up with a workable solution. Many graduate students in engineering will have some or all of their thesis work in the area of engineering design. Often students have elements of both hypothesis-driven research and design work as part of a thesis or dissertation. When examining ethical issues in design, it is important to understand the design process.

The first step is to clearly identify the problems being address and the design goals. When setting design goals, an engineer is required to make choices on priorities. For example, in designing a bridge one may choose to design with a factor of safety of 2 or a factor of safety of 10. The lower factor of safety may be cheaper to build but carry greater possibility of failure and the engineer has to choose an acceptable level of risk and an acceptable level of cost. In addition, there is a need to be thorough on assessing the design goals to avoid unforeseen issues. An example of such a need was illustrated by the Challenger disaster where engineers did not thoroughly consider the need to design for some temperature conditions resulting in failure under cold temperatures.

The second step is to develop a preliminary design (or sometimes several preliminary designs) and assess it against the design goals. Testing of a design often involves hypothesis-driven, experimental research and as such, many of the RCR issues apply. In addition, engineering analysis and mathematical modeling may be used to assess a design concept. These first two steps are often repeated as the design and the goals of the design are refined. Once a satisfactory design has been achieved, the design may be deployed to address the design problems. Once deployed, unforeseen problems can arise and require a repetition of the design process.

The ethical issues in engineering design can be quite complex. One is often making choices between competing design needs and those choices can carry with them consequences that impact human life and health, business and product viability, the environment, and society.

Responsible Conduct of Forensics

While a smaller area of engineering, forensic analysis is one that should be considered in RCE. Forensic analysis is the process of using scientific and mathematic principles to describe how some event may have occurred. For example, after the collapse of a bridge, an engineer might be asked to investigate what factors played a role in the collapse. Another example is the use of engineering modeling in assessing injuries in a car crash. An engineer might use such work to testify in court whether or not an occupant's low back pain could have resulted from the events of the crash. In such work, complex engineering analysis, modeling and experimentation may be used and presented to a lay audience. In such work, an engineer's ethics are important as the engineer works under an expectation that they will work only in their area of expertise, that they will accurately represent the science, and that they will not be influenced by conflicts of interest in their work.

Engineering Modeling

With increasing computational power, engineering modeling has grown in prominence. It is not uncommon to see an engineering dissertation where the entire work involves the development and assessment of a theoretical model. Engineering modeling is the process of creating a mathematical representation of a physical system for a variety of uses including the development of research hypotheses, the low-cost iteration of design possibilities, and the analysis of physical events. These models can range from simple mathematical equations used to assess force on a bridge component, to large computational models of weather patterns for prediction of hurricane strength. Like design, modeling has several steps to it. The first step is typically to assess the simplest representation that could mathematically represent a system while not ignoring important physical dynamics. This step involves making assumptions to simplify a system. For example, to analyze the suspension system in a car, one might simplify the car body to a single mass. While the car may, in actuality be more complex, these complexities may not contribute much to how the car behaves going over a bump and may be simply ignored. These assumption choices can cause problems if one later uses the model in situations where the assumptions are not valid. Once the appropriate assumptions are made, a mathematical model of a system can be created.

Most models require some data on the characteristics of a system. This data can contain errors or variability. The next step is often to see how much this variability affects the system by doing an analysis of the sensitivity of the model. Such an analysis is important in understanding the limitations of a model.

Once a model is created, the model can be compared to experimental data in a process known as validation. The process of validation is one of providing validity against known behaviors. This process can be affected by the availability of experimental data. Additional steps in modeling include assessing computational methods for solving a model and assessing the range for which the model is viable.

Ethical issues that can arise in engineering modeling come from the complex nature of such models and the applications to which they are applied. For example, a model of hurricane strength that underestimates the strength of a hurricane could have devastating consequences to the coastal community that relies on such a model to warn its residents. For such a model, the assumptions made in creating the model and the process of validating the model could have a significant impact on human lives.

Beyond what we cover, there is the question of how it should be covered. In the Bioengineering program at the University of Kansas, we have opted for a 1-credit hour course. This has the advantage of ensuring equal coverage for students taking a diverse range of other graduate course. However, it is isolated from other courses and faculty and so can face the challenge of being appropriately integrated. Undergraduate "engineering ethics across the curriculum" programs present new possibilities in RCE presentation, namely embedding content within existing engineering courses. While this option has attractions including the involvement of multiple faculty and the integration with engineering materials, core curriculum are less common at the graduate level making this option difficult to implement. One possibility that has not been tried, but might be considered is a program of RCE materials presented in the laboratory. Materials could be created for use by a faculty mentor at laboratory meetings or one-on-one meetings with graduate students. As many students learn elements of RCE from their faculty mentors, such materials could be used to provide support for faculty mentors and create a more structured presentation of such materials in the environment they are most commonly implemented.

[1] *National Academy of Sciences, National Academy of Engineering and the Institute of Medicine*, 1995, *On Being a Scientist: Responsible Conduct in Research, Second Edition*, National Academy Press, Washington, DC.