2006-16: ON THE STRUCTURING OF THE GRADUATE ENGINEERING DISQUISITION

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On the Structuring of the Graduate Engineering Disquisition

Abstract: It is well-accepted that since the career roles of humanists, scientists and engineers are different, so too should be their academic preparation. This paper contends that the differences in disciplinary preparation extend to a differentiation in the structuring of the research thesis or dissertation (disquisition). In turn, the structure of the disquisition shapes the topical definition, the scholarly investigation and the character of the reported result. A methodology for structuring the graduate disquisition is offered that is based upon the unique character of engineering scholarship, quite distinguished from research in the humanities and sciences. In describing a framework for the disquisition, the paper outlines an approach to scholarship that is expressly focused on engineering and its societal responsibilities.

The structure presented has been employed with the graduate students supervised by the author. An eight-chapter disquisition outline is presented, along with supplemental procedures for managing throughput and for composition of the supervising committee that includes knowledgeable practitioners, as well as faculty. Some examples of successful disquisition topics and committees are presented. The paper concludes with a reflection on the opportunities for and barriers to wide-spread adoption of an engineering disquisition focused on innovation and design, as contrasted with one concentrated solely in discovery.

Context and Purpose of Graduate Education: Formal post-baccalaureate study in virtually every discipline culminates with the preparation of a significant formally-written document that reports original work conducted by the graduate student. Regardless of the discipline of study, the document reports the results of a scholarly investigation through which the student demonstrates abilities to independently identify and define a significant issue in a relevant field, to undertake a substantive examination of the issue and to compile a cohesive discussion of the investigation and its results. The resulting work is variously referred to as a thesis, a dissertation or a disquisition.

This general description is commonly taken to apply to social sciences, humanities and physical sciences, as well as to all engineering fields. However, the outcomes expected in the post-degree careers of humanists, social and physical scientists, and engineers are quite different. The scientist and humanist are charged with discovery. Their task is to learn and, then, to explain to their peers the nature of their discoveries. Quite to the contrary, the engineer is expected to develop a command of a defined topical field and, more importantly, to apply that knowledge in a very tangible way that benefits society -- and, then, explain both discovery and application to society.

Core Competencies in Engineering: All engineers solve problems and all engineers design things. The central differentiation of engineering from other disciplines is captured in the famous adage ascribed to Theodore von Karman, which can be lightly paraphrased as, "Science discovers what is; engineering creates what never was." At the core of all engineering disciplines is the notion of design. This is the essence of the engineering profession. Some engineers design products; some design processes. The intellectual modus operandi is the assembly of diverse factual information, critical analysis of these data in the framework of the relevant scientific relationships and, from this foundation, the creation of a solution to a problem of importance to society. This 'engineering method' is founded on a clear and concise statement of purpose -- a crisp definition of the problem to be solved and of the metrics through which to judge if and to what extent a solution has been achieved.

The problems to be solved and the things that are designed are what differentiate the various engineering disciplines. These differentiating factors, in turn, lead to the designation of specific subject matter to be embraced within the disciplines. The subject matter of mechanical engineering, for example, traditionally includes solid mechanics, dynamics, mechanical product design, fluid mechanics and thermodynamics. The author's discipline of manufacturing engineering has been well-defined as comprising product engineering and engineering materials, process science, quality engineering and production systems engineering.[1,2] Other engineering disciplines are defined in parallel fashion.

Engineering research, which is central to graduate study, is characterized by both discovery and application -- by creation of something new. This often leads the research into paths somewhat afield from traditional sub-disciplinary topical definition. One of the challenges, thus, of the faculty advisor is to balance attention to recognizable disciplinary fundamentals with the creative spirit of the graduate student researcher. Experience suggests that recognized accomplishment in the core competencies of the engineering field are best focused in the coursework. The research should be guided with a looser rein.

Intellectual Character of Graduate Study: Increasingly, engineering work in both industry and in academic preparation is undertaken in project form, most often through multi-disciplinary teams. In the graduate education context, engineering students are traditionally expected to undertake, complete and document an independent project of significant scope. The 'significant scope' dimension often clashes with 'independence', as many of the relevant problems in current-day engineering are multi-disciplinary, or at least multi-dimensional, and are best addressed by teams.

The graduate disquisition is intended to be a substantive intellectual product. The project nature, as well as the often multi-disciplinary character, of relevant engineering work can at times be interpreted in some academic quarters as 'non-intellectual'. It is both prudent and responsible, therefore, that engineering faculty take pains that the project work of their graduate students is appropriately intellectualized.

The engineering professor supervising graduate students has, in this sense, a two-fold objective: to direct the project work through the full engineering process and to assure that the project work embraces adequate intellectual character. The 'engineering process' can be characterized as … topical mastery -- problem definition -- data assembly -- modeling and analysis -- design -- validation -- assessment -- documentation. Project-oriented design work remains of central importance. Thus, the challenge becomes one of intellectualizing a project. It is postulated that this challenge can be fulfilled in three ways: [a] including a substantive examination of the prior literature; [b] maintaining rigorous research procedure; [c] critically assessing the work and projecting its relevance into the future. Each of these intellectualizing elements can be seamlessly woven into the conduct of design-focused research work and, thus, can flow smoothly into the disquisition.

A Model for the Engineering Disquisition: The author supervises a large number of engineering graduate students in both masters and doctoral study. During calendar 2005, for example, this roster included two students pursuing the PhD in Industrial and Manufacturing Engineering and twelve seeking the MS in Manufacturing Engineering, Industrial Engineering and Management or Mechanical Engineering. Four MS degrees were produced during this calendar year, and two additional students successfully defended and are completing the final thesis re-writes during early 2006. At the time of this writing, two additional MS degrees are expected to complete in the Spring semester.

In order to achieve a modicum of efficiency in instructing a relatively large roster of graduate students, the author devised and adopted a written set of guidelines for graduate student disquisitions. In turn, the fixed structure for the disquisition guides the entire research process. The guidelines provide a platform for inclusion of critical elements of engineering graduate study and its documentation: intellectual foundation, discovery and application.

These guidelines are the result of reflection on several decades of engineering practice and teaching, rather than emerging from concentrated study of techniques employed by others. Reference to published work is implicit, rather than explicit. The document reflects classical engineering problem-solving procedure, recognizable design methodology and the ‘engineering method’. This guidelines structure was introduced to the author’s roster of students in mid-2004 and is now used by every graduate student under supervision, in whatever discipline.

The following section is a verbatim reproduction of the disquisition guidelines. It is presented in this form in order to offer the full flavor of the guidance followed in supervising graduate research projects. While there are several references to explicit sources on the author’s campus, these could readily be converted to companion services available on virtually any campus in the United States.

Guidelines for Preparing Theses and Dissertations

A thesis or dissertation (disquisition) is a complete and comprehensive document that demonstrates scholarship, original thought and effective communication. While there may be occasional variations, the disquisition will most often contain eight chapters:

1. Introduction
2. Display of the relevant body of knowledge
3. Definition of the problem to be solved in the work
4. Analysis
5. Synthesis of a solution to the problem being addressed
6. Validation of the designed solution
7. Conclusions and assessment of the utility of the work
8. Discussion of future directions for similar research

These chapters will always be followed by a comprehensive bibliography, presented in an engineering format (as opposed to one favored, for example, by the Modern Language

Association). There are frequently, also, one or more appendices where complete experimental data, equipment specifications, and similar relevant detail are presented. The disquisition will be started by a title page, abstract, table of contents, list of illustrations and other front material. The NDSU "Guidelines for the Preparation of Disquisitions" contains directions for the necessary front material. An optional front element that is a nice touch is a dedication. In this, you get an opportunity to acknowledge those people who have been influential in your professional growth, especially those who are not directly involved in your research team or disquisition committee.

The first task in preparing a disquisition is the selection of a title. Titling is a modest art form, aiming for the often-conflicting goals of accurate reflection of content, crisp brevity and attractiveness to readers. Several iterations may be required before a good title is devised. Smaller versions of this task arise for every major and minor section of the disquisition. Each section should be titled creatively and accurately, and with brevity. Likewise, every illustration will be titled -- briefly and completely.

All disquisitions will be written in effective and attractive English. Grammar, syntax and vocabulary will be professional in all respects. There will be no spelling errors. Every student will be expected to develop a sound professional writing style. It is to be expected that virtually all students will benefit to a very great degree from the services of the Center for Writers and, perhaps, other sources of instruction and consultation.

The Disquisition

Chapter 1; Introduction: The purpose of an introduction is to introduce. You introduce the reader to the context of the work. This is done through describing the tropical area, positioning the topic in the industrial landscape, relevance to society, purpose and/or other aspects of your work. If, for example, you are working in designing new methodology for scheduling of concurrent engineering product development, your Chapter 1 should introduce the reader to product development and speak to why it is important. If you are developing new methods for assembling microelectronic devices, your Chapter 1 should address the landscape of microelectronics fabrication and identify the portion of that spectrum where your work is concentrated. Chapter 1 should be of only modest length.

Chapter 2; Display of the relevant body of knowledge: This chapter is a display of your erudition. It is sometimes known as a literature study, but it is always much more than that -- and is never merely a literature survey. It should be a scholarly exposition of the current state of knowledge in your subject area.

The literature you consult should be comprehensive. It is normal to start with books, but keep in mind that, because of publishing procedures, the information contained in books is some years old on the date of publication. Journal papers are somewhat more current, but still a bit dated, as the peer review process can take several months to a year, or more. Conference papers are the most current, usually reaching publication in a matter of a few months after the work is done. When you consult internet sources, be careful. Web site content is often not subject to independent review and verification. There are many reputable sites, but there are also others not so reliable. Also, downloaded hard copies frequently lack source identification, and the references you cite in your writing must be verifiable (author, title, place of publication, date). Citing a bare URL is not adequate. Treat web sites like journals; identify your source by URL, page, author (if available) and date. At times, it is appropriate to cite information drawn from commercial sources (e.g., user manuals, equipment specifications, etc.). However, any substantive or foundation information should be corroborated from an independent source.

At the start of almost every disquisition, the literature survey begins as an annotated bibliography -- a brief litany of sources consulted, with a few words about what each of the authors is writing about. This is only a start. An annotated bibliography talks more about the literature vehicles than about the content. The disquisition chapter should be focusing on the 'what', 'how much' and 'how' of your topic -- occasionally, 'when' is important. These issues are nearly always more important than 'where' or 'who'. Leave the identity (and verification) of sources to the bibliographic references. What a disquisition should contain is an exposition of your erudition. This should be a seamless presentation that captures the existing body-of-knowledge of the selected topic in an effective, intellectually-sound capsulized fashion. You are telling a story. Think of this chapter as a primer that can be lifted out of your disquisition and used to instruct others in your topic. It should read like a chapter out of a textbook. Your objective with this chapter is to establish yourself in the mind of the reader as an authority on the topic you are addressing. Chapter 2 can, thus, be somewhat extensive.

<u>Chapter 3; Definition of the problem to be solved in the work</u>: This chapter should be a clear and concise statement of the focus of your research -- the particular problem within your topical area that you are attempting to solve. State the objective of your research (what you are trying to accomplish); outline the methods you use (e.g., theoretical derivation, laboratory experiment, data gathering survey, etc.); introduce the outcome to be achieved (e.g., a new or improved manufacturing process, a new or improved engineering procedure, etc.). The latter part should clearly indicate the metrics that determine when the objectives have been achieved and the stated problem solved. This discussion should also provide a clear appreciation of what the work does <u>not</u> encompass. Chapter 3 should be short and to the point.

<u>Chapter 4; Analysis</u>: This is a critical phase in the design process. Engineering is a quantitative profession. Its qualitative side grows out of definitive quantitative reasoning. Good engineering work will examine alternative methods for solving the problem at hand, apply the relevant theory, compute and interpret numerical data.

Analysis, in almost every situation, involves common elements: problem statement (see Chapter 3); pictorial description (e.g., free body diagrams, process flow maps, schematics, operational sketches, part drawings, etc.); gathering of input data; modeling (analytical, computer, physical, etc.); computation of output data; examination of output data and presentation in the most illustrative forms. Good analysis requires creative modeling, diligence, disciplined execution and perceptive observation. Your mathematical skills will be on display here. Chapter 4 will be as long as it needs to be. Most often, it will contain frequent and extensive illustrations -- equations, tables of data, sketches, charts, graphs, etc.

Chapter 5; Synthesis of a solution to the problem being addressed: Engineering is a profession that designs things. Different engineering disciplines design different things -- some are products; some are processes. In manufacturing engineering and industrial engineering, we design processes. Remember that design is a procedure that creates something -- remember Theodore von Karman's famous maxim: "Science discovers what is; engineering creates what never was." This portion of your work and this chapter of your disquisition are central to your positioning within the profession of engineering.

So in this chapter, you will present the process that you have created to address the problem defined in Chapter 3. Your design can take many forms. How the design is described and presented (i.e., its form) will be determined by the topic and the problem (see Chapter 3). It virtually all cases, a diagram of some sort will be a central feature -- a process flow map, equipment sketch, part drawing or some other form. The design description will also have a quantitative aspect. If, for example, you are designing a new process for manufacturing electronic goods, you should define (at least) the size of components that are accommodated and the rate at which the production occurs. Chapter 5 will also be as long as it needs to be, although it will usually not be as lengthy as Chapter 4. This chapter will also contain a high fraction of illustration.

Chapter 6; Validation of the designed solution: In engineering, whatever we design is intended to work -- to do whatever it is that we intended. Thus, the research work concludes with a test of the newly synthesized process to validate that it is truly a solution to the featured problem. This is almost always an experimental effort. If possible, it should be carried out in conjunction with an industrial partner.

The first task in this segment of the research is to determine what features of your design must be examined, what characteristics will provide the appropriate measure of performance and the methods you will use to make the measurements. You will design a set of experiments to test the most pertinent characteristics, establish the experimental apparatus or situation, conduct the experiments, gather and interpret the data. In some cases, design of the validating experiments could be included as part of Chapter 5. In either case, Chapter 6 will be a complete record of the experimental work undertaken to validate the proposed design solution. At the end, you will use the experimental data to confirm the validity of whatever was designed (as described in Chapter 5). Chapter 6 will usually be about the same magnitude as Chapter 5.

Chapter 7; Conclusions and assessment of the utility of the work: After the heavy work of experiment is concluded, it is necessary that you (the person who knows most about this subject) sit back and assess what you have created and accomplished. The penultimate chapter of the disquisition is your own assessment of your accomplishments. What are the important lessons learned in this work? What advice on how to do research in this topic can you pass on to others? Then, draw conclusions about your work. Assess the utility of your research. How should your results be applied? What are the limitations? What works? What doesn't work so well -- or works only in certain situations or under certain conditions? What doesn't work at all? In what situations should your design be applied? Where should it not be applied?

This is a crucial part of your research. And it is, perhaps, the most intellectually challenging aspect of your thesis. You must be able to think expansively, to project beyond the somewhat more mechanistic tasks of analysis, synthesis and experiment. You must also be self-critical. While this is difficult to do, candid intellectual honesty is a hallmark of the scholar. It is an important potion of the learning process in post-graduate study. Chapter 7 need not be a lengthy discussion, but your intellectual ability is on display here and will be closely scrutinized.

<u>Chapter 8; Discussion of future directions for similar research</u>: Throughout your research, you will have encountered interesting and important questions that should be addressed, but which were outside of the scope of the current work. These are gems for those who come after you. During the course of your work, you should keep track of these related issues and questions (your intellectual property journal is the ideal place for such records). The ultimate disquisition chapter is your collected view of the work that should be undertaken to carry your work forward.

Again, this is an exercise of your intellectual prowess. You know better than anyone where exploration in your topical area should proceed. It is part of your duty to the profession to provide a measure of guidance for those who follow. Chapter 8 is not likely to be long, but it should be very well crafted.

Implementation: Employment of this structured approach to the disquisition simplifies two matters of administration and substance that often are problematic: time management and engagement of industry. These are related issues, as the industrial mind-set tends to be more attuned to managing projects against a defined time-line.

<u>Degree Completion Schedule</u>: A common practice for graduate students is that when employed in assistantships, they are half-time students and half-time employees. The simple translation for working at student responsibilities only half-time is that the time required for completion of academic requirements stretches by a corresponding factor of two. Thus, a one-year, thirty-credit masters' program stretches to two-years. Under these conditions, a doctoral program may extend to four post-MS years. Moreover, as in undergraduate study, it is not uncommon for students to stretch-out their programs even further for a variety of reasons. For graduate students supported on assistantships, unanticipated lengthening of the duration of study can introduce awkward complications in regard to sponsorship. In a similar vein, some universities apply a throughput metric -- rating academic units more on degrees produced than on graduate students enrolled.

The disquisition structure helps in this matter by providing simple and easily portrayed milestones. A time standard for a masters' degree student working on a research assistantship might be two years -- say, four semesters and the intervening Summer. The model evolved for the author's graduate students starts with each student completing nine credits of coursework in each of the first two semesters. This will satisfy the core competency requirements for the degree and, usually, provide some opportunity for coursework in specific support of the thesis research. Additional coursework is most often undertaken to support the research effort.

In addition, each student will undertake some serious study of the literature in search of thesis definition. Selection of a research topic is most often a challenge for young graduate students. As undergraduates, they were accustomed to having their projects selected and defined by their professors. In graduate study, the student is expected to be knowledgeable enough to understand his or her discipline sufficiently well to be able to identify the significant issues. Likewise, students are expected to be mature enough to know their own capabilities and true interests. Alas, this ideal is seldom realized, and the professor has the task of guiding the student through a bit of intellectual maturation. Our practice is to engage the graduate student in close-coupled dialogue throughout the first year, guiding him or her through the process of discovering and defining the thesis topic -- always with the disquisition structure in front of us.

The Summer term is an excellent opportunity for concentration on the thesis. With a foundation of the first two-semesters of searching for topical definition, a substantial portion of the literature study can be completed during the months when coursework is generally not active. It is quite reasonable to direct the student through the writing of the first draft of Chapters 1, 2 and 3 by the end of the Summer. In parallel with the literature review, it is often helpful to guide the student into the drafting of a journal or conference paper. This helps the student to make the transition from an undergraduate-tendency towards annotated bibliography into a proper examination of the literature in the context of the defined thesis problem.

During the second Autumn semester, the remaining coursework can be completed, as well as finishing the collection of the necessary external data and conducting whatever analytical examination is to be done. The disquisition milestone is Chapter 4. It is also very advantageous to draft Chapter 5 and define the experimental procedure for Chapter 6.

With this foundation built and coursework completed, the Spring semester can be concentrated on the validation experiments, assessment, writing of Chapters 6, 7 and 8, finishing the editing and re-drafting of the disquisition document, and the defending the thesis. In the event that any substantive fabrication of experimental apparatus is to be done, it is especially important that as much of Chapters 5 and 6 as possible are completed during the prior semester. The Winter semester break is an extremely valuable time for equipment set-up.

If all goes well, the defense can be completed in, say, April and the degree awarded in May. Thus, a Master of Science degree can be completed in five semesters (including a Summer) -- by a student also employed as a research or teaching assistant. Experience indicates that a schedule this tight is seldom achieved. In the author's somewhat limited experience, it would seem that six or seven semesters is a more realistic expectation for a good student.

Doctoral students are normally expected to have completed the bulk of core competency study in masters' degree coursework. Post-MS formal study will, thus, concentrate in more advanced methodology and in topical depth in direct support of the dissertation topic. In this regard, the doctoral student ought to be challenged to draft a Chapter 1 and at least a rough cut of Chapter 3 during the first semester in doctoral residence. This will help to provide a focus for selecting coursework that will most effectively support the dissertation research. Formal coursework and a doctoral-level literature study can be completed in the first two or three semesters, so that qualifying examinations can be completed by the end of, say, the third or fourth semester in residence. The remaining milestones are best managed individually.

Industry Participation: The fundamental premise throughout this treatise is that graduate engineering work is not only scholarly, but also relevant and practical. The best way to insure this is to engage industrial practitioners in the research in a meaningful way. This, of course, can be accomplished in several ways. Experience suggests that it is best to include an engineering practitioner in an official oversight capacity -- i.e., as a member of the supervising committee. That usually provides adequate ownership for effective committee participation. The preferred composition of the supervising committee will be the usual two (or more) faculty from the degree-granting department, one (or more) faculty from another academic unit and one (or more) engineering expert from industry.

Industry involvement is, naturally, better when there is real partnership in the conduct of the work. Often the industrial firm will have more suitable equipment, and in this case, it is advantageous to conduct the experiments within the industrial facility. This generally is more easily arranged when the industrial company is providing monetary sponsorship, but often access to specialized apparatus be arranged outside of formal sponsorship.

Experience: Although the written format of the disquisition structure outlined in this paper has only been in use for two years, the general concept has been applied for some time longer. It has evolved and matured for about six years, in all. It is fair to say that there are fourteen graduate students operating in what can be construed as five research teams that are working (or have worked) under this methodology. Tabulation of the research topics for these students indicates that the disquisition structure is effective across a variety of subject matter and disciplinary orientation.

Research Teams:
self-assembly of micro-components
* simultaneous fluidic self-assembly of meso-scale integrated circuits (a;f;h)
* modular localized fluidic self-assembly of micro-devices (a;f;h;i)[3]
* predictive model for surface tension forces in micro-assembly (c;h;i)[4]
* dynamic behavior of micro-particles descending through a liquid medium (a)

printed electronics
* process engineering for stencil printing of representative features of micro-batteries (a;f,g;i)[5]
* process engineering for stencil printing of antenna forms for wireless microsensors (a;g;i)[6]
* predictive model for screen printing of microsensor antennas (a;f,g)

assembly of printed circuit boards
* effects of lead finish on solder joint integrity (a;e,f,g;i)[7]
* management and mitigation of electro-static discharge in printed circuit board assembly (a;e,f,g;i)[8]
* alternate soldering methods for lead-free printed circuit board assembly (d;e,f,g)

applications of radio-frequency-identification technology

* strategies for applying radio-frequency-identification for combating pharmaceutical counterfeiting (b)
* applications of radio-frequency-identification in process control and supply chain integrity in food processing (d)

manufacturing management

* management of concurrent engineering product development by means of Theory of Constraints (b;f,g;i)[9]
* template for evaluating the business case for continuing engineering education in small manufacturing companies (a;f,g;i)[10]

a	Master of Science, Manufacturing Engineering	9 projects
b	Master of Science, Industrial Engineering and Management	2 "
c	Master of Science, Mechanical Engineering	1 "
d	Doctor of Philosophy, Industrial and Manufacturing Engineering	2 "
e	industrial sponsorship of the project	3 "
f	industrial participation in the research	9 "
g	industrial member on supervising committee	8 "
h	research yielded a patent disclosure	3 "
i.	completed	8 "

Barriers: It is acknowledged that traditional notions of a master of "science" and the doctorate may, in some quarters, be at odds with an engineering MS or PhD based upon innovation and design. Objections have been raised to the effect that innovation and design are not sufficiently rigorous for academic recognition. It is suggested here, however, that the approach propounded in this paper is, in fact, more rigorous -- requiring both traditional scholarship of discovery (as evidenced by extracts from the literature and comprehensive analytical content) and scholarship of application (in the form of problem solution, experimental validation of the designed solution and assessment of the design).[11] Still, one of the potential barriers to acceptance of design-based graduate engineering degrees is an entrenched attachment to 'purity' of the science.

Another campus-centric issue is the dearth of engineering faculty who have real experience in the challenging environment of implementing theories in real industrial settings. 'Engineering' that encompasses the gamut of analysis, design, validation and assessment is difficult to master from experience confined only to an academic setting. In particular, it is very difficult in all cases to master the art of compromise that infuses engineering work done amidst the conflicting imperatives of a customer-driven industrial setting. Without having lived and survived in such a setting, full understanding is illusory.

There are also a number of issues in the industrial connection that must be addressed. It would seem that every industry-university project struggles over the issue of timeliness. The conflict between accustomed timelines of industry and academia is an old story. However, as the disquisition research becomes more directly usable in currently marketable products or services, industrial urgency increases. There is a flip side, as well. When the project is not assigned a reasonable priority by the sponsoring company, other urgent matters are likely to absorb the attention of the industrial partner and vital project delays will usually ensue. Another critical issue revolves around proprietary information. This has always been a matter to be addressed, but has received sharper attention in recent years. Increasingly, both industrial firms and universities are sharply aware of the potential value emanating from intellectual property. Reaching and maintaining effective agreements in this regard is a decidedly non-trivial challenge.

Additional barriers to industry support of and participation in engineering graduate education also exist from the corporate perspective. Financial sponsorship of the graduate student's project is always a serious issue. The business case must be made. With or without a financial commitment, company management is often reluctant to authorize usage of corporate resources (including valuable engineering time) for 'non-productive' activity. Thus, the knowledgeable engineer may be expected by his or her management to participate in advising a graduate student only outside-of-work-hours. In addition, this type of activity may be rated as neutral or negative during performance evaluations. A similar reaction may arise from requests to use specialized apparatus in the company laboratory or plant, even when scheduled off-shift.

A more insidious situation sometimes arises when the student has a skill-set that fits a current company need. It is not unknown that a company partnering with a university team will hire one or more of the students assigned to the project by the academic unit. While this is a very desirable goal for students who complete their degrees, it is ruinous to the academic department when the hiring is done before the student finishes the degree. The situation becomes particularly difficult when the company does not communicate their interest to the student's academic supervisor. When a student is hired early, degree completion is delayed significantly. A good rule-of-thumb is that, in the best of cases, the time required to write the disquisition is expanded by a factor of, at least, six. If the place of employment is far enough away from the campus that regular (at least fortnightly) meetings between student and advisor are not feasible, or if some amount of research work remains to be done, the degree delay can become much longer.

Adoption: The most important factor for successful application of the procedures described in this paper is establishment of a close mentoring relationship between faculty, industry practitioner and graduate student. Experience and the literature suggest that there are two critical elements needed to achieve such relationships.[12] Frequent substantive interaction is necessary. It is suggested that faculty advisor and graduate student meet not less frequently than once per week for not less that one hour. Although highly desirable, meetings with the industrial advisor can probably be safely scheduled with slightly more spacing. The meeting format should parallel widely-followed practice for project meetings in an industrial setting -- agenda: what was done this week; evaluation of the weekly results (in the context of project objectives); what needs to be done next week; assessment of the resources available to do what needs to be done; task setting for next week.

An important second element in project success is a certain amount of socialization. The faculty and industrial advisors ought to get to know the graduate student outside of faculty and company offices and laboratories. Graduate work is appropriately characterized as more like a partnership between advisors and student. This requires a familiarity well beyond the norm.

The second key element in successful adoption of design-centric engineering graduate program is developing and maintaining close relationships with relevant industrial partners. Over the past several years, this topic has been among the most prominent in engineering education conferences and journals; so, no attempt will be made here to add another wrinkle on how academy-industry partnerships can be grown. The important point is that these relationships are vigorous and well-maintained.

From the industry side, it is essential that the relationship with the academic unit is seen by senior management as a strategic value-adding activity for the corporation, with appropriate assignment of adequate resources. From the academy, both faculty advisor and graduate student must appreciate the time imperatives and results orientation of the industrial world -- and respond to these forces in the structure and conduct of their work.

The prime factors in this equation are faculty devotion of effort and will and serious commitment by the industrial partner. It takes time and dedication to nurture a strong body of graduate students. Likewise to build effective relationships with an industrial constituency. It is, however, an achievable objective, given the will and some energy. Effectively applied, the procedure presented in this paper can be expected to yield … [a] disciplined and well-managed graduate student research; [b] efficient passage of students through to their degrees; [c] graduate student learning that is focused on engineering innovation and design; [d] high standards of intellectual content in design-centric engineering graduate work.

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