A QUALITATIVE ANALYSIS OF ENGINEERING DESIGN EDUCATION IN A BIOSYSTEMS ENGINEERING DEPARTMENT AT A CANADIAN UNIVERSITY

BY

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Abstract

Increasingly, undergraduate engineering programs in North America are criticized for the inequitable weight given to science curriculum over design curriculum in engineering, and for the perceived lack of integration between engineering science and engineering design. The effects are alleged to be engineering graduates with poor design understanding and competencies. A Department of Biosystems Engineering at one Canadian university facilitates design education through a course model named Biosystems Engineering Design Trilogy (DT). The DT consists of three courses in second, third, and fourth year of the curriculum with integrated content and instruction. This study consisted of a qualitative research process that critically examined the perceptions of students, instructors, an administrator, and industry cooperators regarding engineering design education in the DT model. Research questions were developed to discover participants' concepts of engineering design; critical goals, teaching and learning strategies in design education; and reflections on the DT structure. One-on-one and focus group interviews provided a comprehensive data set describing the experience of design education from multiple perspectives. The findings yielded many commonalities between participants' conceptions of design education and a literature-based conceptual framework developed to support the study. The results also illuminated instances where perceptions of students and industry cooperators did not correspond to the intentions of instructors and the program, respectively. Implications of these findings included the importance of transparency and integration in teaching, collaboration between instructors, communication between instructors and students and between the university and industry cooperators, awareness of the unique nature of the DT model within the undergraduate engineering curriculum, and institutional considerations that affect the success of teaching and learning endeavours.

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Chapter 1:

Introduction

Pressures on Engineering Education

Increasingly, undergraduate engineering education is being criticized for the lack of design skills and design competencies of engineering graduates. This criticism comes from the practice community (Nicolai, 1998; Lang, Cruse, McVey, & McMasters, 1999; Sheppard & Jenison, 1997), from accrediting bodies (Accreditation Board for Engineering and Technology, Inc., no date; Canadian Council of Professional Engineers, no date), and from government granting agencies in both Canada and the United States (Natural Sciences and Engineering Research Council, 2001b; National Science Foundation, no date; National Research Council, 1991). The particular skill set that these critics would like to see strengthened are not necessarily related to the engineering science components of the curriculum, but rather the creative process of design and the 'soft' skills that facilitate this process.

Criticisms centre on the inequitable priority given to science curriculum over design curriculum in engineering, as well as the perceived lack of synthesis or integration between engineering science and engineering design in the curriculum (Dym, 1999; Gibson, 1995). The effects of this curriculum structure are alleged to be engineering graduates with poor design skills, a lack of practical experience, and a lack of understanding of design process and orientation. These shortcomings are seen to have subsequent broader negative effects on the competitiveness of entire industries and North American economies relative to the remainder of the developed world (Nicolai, 1998; Gorman et al., 2001; Lapins, 1997). While criticizing the status quo, these same organizational bodies and groups are responding constructively with initiatives to develop engineering design education. These responses have taken the form of changes to curriculum requirements for accreditation that enhance the visibility and priority of engineering design education, as well as funding for curriculum initiatives in engineering design education such as the Chairs in Design Engineering program initiated by the Natural Sciences and Engineering Research Council (NSERC) in Canada. These criticisms and some of the recommended solutions have evolved from the recent history of engineering education.

The shortcomings of the undergraduate engineering curriculum in North America have been articulated in different ways, but generally always contrast a lack of design emphasis to an over-emphasis of engineering science, theory, and/or analysis in the curriculum. The roots of the current curriculum structure are commonly traced to the Grinter Report published in the US in 1955. The Grinter Report was the final report of the Committee on Evaluation of Engineering Education of the American Society of Engineering Education appointed in 1952. The charge to the Committee was

> to recommend the pattern or patterns that engineering education should take in order to keep pace with the rapid developments in science and technology, and to educate men [sic] who will be competent to serve the needs of and provide the leadership for the engineering profession over the next quarter-century (Grinter Report, 1955, cited in Harris, DeLoatch, Grogan, Peden, & Whinnery, 1994, p. 69).

The committee consisted of 46 men, chaired by L.E. Grinter. The final report was published in September 1955 and received wide support from university, industry, and government communities.

In retrospect, the impact of the Cold War on the concerns of engineering education as expressed in the report is evident, with an emphasis on the service that engineering education gives to US national priorities (Harris et al., 1994). The report was interpreted very narrowly and has become widely seen as beginning the now well-entrenched curriculum shift toward engineering science – and away from engineering design – in North America. Following WWII and in the glow of engineering achievements such as Sputnik that would have been impossible without the contributions of physics, the advocates of engineering science had succeeded in transforming the engineering curriculum into an education in applied physics. This curriculum, heavy in science and mathematics, was directed at helping engineering students better understand the complex principles involved in modern technological developments. The curriculum developed students who were strong in research but generally unfamiliar with engineering practice. Aided by the enormous public support for science in the period 1953-1967, engineering schools had placed their bets on an engineering science oriented to the 'possibility of the new' rather than to the 'design capability' of making something useful. With this shift in emphasis, the specialist in a discipline became the most powerful member of the engineering faculty. Practicing engineers were no longer powerful role models when the professors of highest status were engineering scientists with little or no industrial experience, and by 1967 engineering design had virtually disappeared from the curriculum (Schön, 1983; Ferguson, 1992; Dutson, Todd, Magleby, & Sorensen, 1997).

Interestingly, the Grinter Report noted repeatedly that the recommendations of the Committee were not to be used as restrictive quantitative requirements, and the

Committee encouraged institutions to experiment with engineering curricula. Furthermore, the report made a total of ten recommendations related to the engineering curriculum. The first recommendation advocated for strengthening of work in the basic sciences and the second called for the identification and inclusion of six engineering sciences taught with full use of the basic sciences as a common core of engineering curricula. However, the remaining eight recommendations addressed integrated study of analysis, design, and systems; elective subjects, humanistic, and social sciences in the curriculum; communication competencies; the use of experiments; strengthening of graduate programs; and, steps to maintain faculty resources (Harris et al., 1994). Unfortunately, it is widely recognized that the Grinter Report was interpreted narrowly and has become almost synonymous with calls for an engineering curriculum devoted to engineering sciences (Bender, 2001).

Engineering Education in a Broader Context

The legacy of the Grinter Report and the history of the last 50 years have brought engineering education to a point where faculty and administrators can recognize the implications and liabilities of current educational paradigms, and where positive momentum toward change is building. It is also useful to recognize that the criticisms levelled at engineering education fit into a larger context of issues that plague professional programs at the university in general. Design is often articulated to be *the* essence or heart of engineering practice (Koen, 1985; Dym, 1999; Tsang, Van Haneghan, Johnson, Newman, & Van Eck, 2001). The fundamental tension apparent in the 'science versus design' debate of engineering curricula can be seen within the broader framework of the 'theory versus practice' debate that many professional programs struggle with as they structure their curricula and learning experiences in response to needs expressed by their external community stakeholders.

It is noteworthy that formal professional knowledge rooted in an *academic* knowledge base creates the conditions for the essential pedagogical problem of professional education: the relationship between theory and practice. The role of theory has been identified as problematic for at least two reasons. First, it achieves its power through simplification and narrowing; research that informs theory is often conducted under controlled conditions with only tenuous connections to the everyday world of practice. Second, theories generally operate within discrete disciplines, in contrast to practical problems that generally cross discipline boundaries. However, negotiating this tension between theory and practice is imperative, since the very nature of professional practice involves both a scholarly or theoretical understanding, a domain of skilled performance or practice, and most importantly, an integration of the principles of theory and the narrative of lived practice (Schulman, 1998).

The theory – practice divide is strongly and deeply embedded in North American research universities and higher education institutions. The epistemology of practice dominant in North American universities has been termed Technical Rationality, which has four essential properties: it is specialized; it is firmly bounded; it is scientific; and, it is standardized. This epistemology is implicit in the institutionalized relationship between research and practice and in the normative curricula of professional education. From a Technical Rationality perspective, real knowledge lies in the theories and techniques of basic and applied science, and thus those disciplines take precedence.

Technical Rationality also dictates that skills, or practice, cannot be learned until a suitable amount of foundational knowledge has been acquired. Therefore, from a Technical Rationality perspective, practice becomes a secondary kind of knowledge (Schön, 1983).

Schön (1983) and Schulman (1998) link the origins of Technical Rationality as an epistemology of practice to the history of Western ideas and institutions, and specifically, to Positivism. In Positivism, science emerged as a dominant force in the universe of knowledge, and since science was housed in the universities, Technical Rationality as an epistemology of practice was also institutionalized in the modern university founded in the late 19th century when Positivism was at its height. Professional schools secured their place in the university in the early decades of the 20th century for various reasons that included degree access, status, or funding access. In return, they accepted the Positivist epistemology of practice that characterized the university.

The standard curricula of other professional programs within the university also demonstrate the normative theory – practice divide, with the theoretical body of knowledge often achieving pre-eminence and earlier exposure relative to practice experience. A well-established pattern of generic professional education can be described as some years of basic training and/or a general or liberal education to establish broad foundations of knowledge. This is followed by years of specialized study with increasingly deep immersion into a specialized content, the acquisition of complex skills, and the value system of the profession. To enhance professional ability, an initial assessment of competence is often followed by a further process in which competence is deepened by guided practice (Houle, 1980).

Undergraduate engineering education in Canada follows this general trend. Some universities require at least one year of general studies prior to admission to the engineering faculty; however, some programs continue to allow a 'direct-entry' option from the secondary educational system for those students deemed academically prepared. In this case, the engineering curriculum carries the responsibility for both broad foundations of knowledge (general or liberal education) as well as specialized professional training. Following completion of specialized training at the undergraduate level, the entry-level engineering practitioner is engaged in a process of guided practice within the workplace, where the employer or supervising engineer, in collaboration with the provincial regulatory body, assesses knowledge, skill, and value development toward a final competency standard. Successful completion of this guided practice legally qualifies the engineer for independent practice. This model has also been observed in other professions, such as medical education in North America following the Flexner report of 1910 (Schulman, 1998; Schön, 1983).

New Directions for Engineering Education

Professionals and educators are recognizing the limits of Technical Rationality as an epistemology of practice. They have become concerned that they cannot account for processes they have come to see as central to professional competence. It is difficult for them to imagine how to *describe* and *teach* what are now considered to be competencies of overriding importance – what is meant by making sense of uncertainty, defining problems, and choosing from among competing solution paradigms – when these processes seem mysterious and non-rigorous in the light of the prevailing model of professional knowledge (Schön, 1983).

In contrast to the existing structural features of the undergraduate engineering curriculum, engineering design education requires the integration of mathematics, basic sciences, engineering sciences, and complementary studies. In further contrast to existing structural features of the undergraduate engineering curriculum, engineering design is defined as creative, iterative, open-ended, experiential, social, synthesizing, and inductive (Canadian Council of Professional Engineers, no date; Sheppard & Jenison, 1997; Gibson, 1995; Bender, 2001). Engineering design education rejects three core dichotomies of Technical Rationality: a separation of means from ends; a separation of research from practice; and, a separation of knowing from doing (Schön, 1983).

In this context, engineering design education is not only an attempt to shift the balance between theory and practice or between science and design. It is also a challenge to Technical Rationality as a valid epistemology of practice, in that it directly challenges its foundational dichotomies. As such, the task for engineering design educators is to find ways, initially, to teach engineering design within the paradigm of Technical Rationality, while at the same time moving the institution toward alternate epistemologies that effectively address the challenges that engineering education faces.

Properly understood, though, engineering has always had the attributes given to design education in the preceding paragraphs, although perhaps not recognized as such. Koen (1985) claims that true engineering has no hint of the absolute, the deterministic, the guaranteed, nor the true. Instead, it is characterized by the uncertain, the provisional, and the doubtful. This again is a reference to the *practice* of engineering, and highlights the incongruence with our traditional models of educating entry-level engineers within academic contexts that have traditionally downplayed or postponed practice.

The goals of engineering design education are broad and varied, depending on whom one asks. For some, learning design is learning a morphology or series of steps to follow in the design process. Texts are dedicated to this approach to designing (Smith, 2000). For others, learning design is learning the complement of knowledge, skills, and behaviours that professional designers use in engineering practice. Others argue that this approach is unrealistic for engineering education, given that university faculty do not possess the complement of knowledge, skills, and behaviours of professional design engineers and therefore are in no position to teach them adequately. Another goal of engineering design education is then said to be to teach the novice engineer how to absorb quickly the set of knowledge, skills, and behaviours of professional design engineers that cannot be taught in school, but can be absorbed in the industrial environment (Koen, 1985).

Without a common base of understanding about the meaning of engineering design, disputes over the appropriate goals of engineering design education will continue. In the current study, a holistic definition of engineering design has been developed which is based broadly in a 'content' of design that is in turn embedded within a 'context' of design. The content of design relates to proposals put forth by various authors that seek to capture what design is, or does. The content of design may be articulated as "a process of transformation of ideas and knowledge, into a description or artifact for further use or function, carried out to satisfy set needs or achieved stated objectives, taking into account constraints or specifications, in a systematic process of generation and evaluation"

(Court, 1998; Sheppard & Jenison, 1997; Dym, 1994, 1994b; Reich, 1995; Smith, 2000; Campbell & Colbeck, 1998).

This design content operates within a context. This context includes a perspective on design that is reflective, creative, and iterative. It further includes information on design that comes from various environmental arenas (the historical, the social, the economic, etc.). Finally, it includes the outcomes of design, which are not only hardware, artifacts, or concepts, but also behaviours and cultural experiences that the hardware, artifacts, and concepts facilitate or shape (Faste, 2001; Moriarty, 1994; Wood, 2001).

Explicitly naming this a *holistic* definition of engineering design asserts the perspective that design cannot be understood simply by an understanding of its parts (e.g. individual steps in a linear process or methodology). Design must be understood as an integrated whole. Engaging in this holistic definition of design through formal design education will likewise require the conceptual and structural components of the teaching and learning experience to be multi-faceted, comprehensive, and integrated one with another.

The outcomes of engineering design education should comprehensively address learning in various domains, including conceptual learning in the cognitive domain, skill and competency learning in the behavioural domain, and value and perspective learning in the affective or developmental domain (Fincher, 1998). To achieve these outcomes, engineering design education must be aligned around a learning theory that supports these outcomes, and a learning theory that can be applied to perspectives that see engineering design as complementary experiential and cognitive activities.

Finally, structural features of each course, including course preparation, administration (pedagogy), and assessment and evaluation of learners must be congruent with the holistic definition of design, multi-faceted learning outcomes, and an integrated learning theory set out for engineering design education. To achieve this congruence also requires attention to numerous pedagogical foci. These foci include the design product or outcome coupled with an understanding and experience of the design process; tools and media used in learning; integration of goals, context, and assessment and evaluation; roles and behaviour of faculty; roles and behaviour of students; and the desired interactions between faculty and students.

While specific formats of engineering design education will differ within and between institutions, attention to the holistic nature of engineering design and the integration and congruence of all aspects of the learning experience are of overriding importance in all instances. This perspective guided the investigation of a particular engineering design education strategy used in a Biosystems Engineering program.

Research Context and Questions

In the late 1990s, the Department of Biosystems Engineering at Western Canadian University (a pseudonym), Canada, introduced a concept in engineering design education, informally named The Design Trilogy (DT). The DT is a set of three courses, taught in second, third, and fourth year of the four-year undergraduate curriculum, respectively. Initially, the DT was an informal collaboration between the courses 34.214 (Introduction to Biosystems Engineering), 34.326 (Design Methods for Machines in Biosystems), and 34.413 (Design Project). As of the 2002-2003 academic year, the DT concept was formalized by withdrawing the above-referenced courses from the curriculum and replacing them with 34.258 (Biosystems Engineering Design Trilogy I), 34.358 (Biosystems Engineering Design Trilogy II), and 34.458 (Biosystems Engineering Design Trilogy III).

Broad conceptual goals of the DT are to expose students to an incremental process of conceptual design through to detailed design as they advance through the trilogy, to present design as both information (subject matter) and experience, to complement design with learning in professional skills and professional practice, and to ground learning experiences in team-based work on authentic, small-scale design projects taken from local industry.

In addition, the three instructors involved in the DT work collaboratively, at times exchanging course sections for a class or two at a time depending on the needs of the specific class at the specific time and the expertise of the instructor. Structurally, the courses are taught in the same timetable section. This allows for all three classes to meet as a group or for teams to be formed between classes, depending on the learning experiences designed by the instructors of the course in any given year.

The DT concept was initiated by faculty members within the Department of Biosystems Engineering in recognition of some of the shortcomings of a traditional compartmentalized approach to course delivery in the undergraduate curriculum, unbalanced focus on individual work and individual achievement in the curriculum, and lack of exposure to engineering design. Over the past decade, the individual design courses that grew into the DT evolved based on the accumulated wisdom and experience, trial and error, and the unwavering good intentions of the course instructors, as well as feedback from students. What has been absent to date is a systematic pedagogical analysis of the DT in its current evolution. Such a systematic pedagogical analysis would assess the extent to which the DT is conceived, planned, and delivered for students to effectively learn engineering design.

Currently, the DT consists of the following three courses, which are described as follows in the 2002-2003 university calendar:

34.258 Biosystems Engineering Design Trilogy I: Biosystems Engineering and its place in the professions of engineering and agrology. Design concepts, with an emphasis on team building and technical communication skills. Philosophy of project planning. Preparation of a conceptual design by teams in response to design assignment submitted by industry. Written report presented orally.

34.358 Biosystems Engineering Design Trilogy II: Advanced design concepts associated with Biosystems Engineering, with emphasis on the principles of safety and human factors engineering. Theory of project planning. Preparation of a preliminary design by design teams in response to a design assignment submitted by industry. Written report with engineering drawings presented orally.

34.458 Biosystems Engineering Design Trilogy III: Advanced design concepts, with emphasis on the principle of quality control. Application of project planning techniques. Principles of owning and operating an engineering consulting company. Preparation of a final design by design teams in response to a design assignment submitted by industry. Written report with cost of services rendered, presented orally.

The DT in Biosystems Engineering is part of a larger emerging design culture in the Faculty of Engineering at Western Canadian University. In January 2001, the Faculty was awarded an NSERC Design Engineering Chair. The Chair provides $1 Million in federal funding to the Faculty of Engineering and charges the chairholder, in this case a long-time former instructor of former DT courses 34.214 and 34.413 (now 34.258 and 34.458, respectively), with developing and implementing initiatives to enhance the presence and effectiveness of engineering design education within the Faculty. Beyond the chairholder initiatives, the Faculty has established new and redeveloped existing first-year design courses. The NSERC Design Engineering Chair has facilitated the creation of a Design Engineering department within the Faculty. This department does not offer a separate degree program per se, but rather supports the development of existing and new design education within existing departments and the establishment of concrete links with design expertise in industry. One initiative under consideration is reproducing the DT model created in Biosystems Engineering in the other departments within the Faculty of Engineering at Western Canadian University (Civil; Mechanical and Industrial; and, Electrical and Computer).

This local context highlights the timeliness of a critical appraisal of the DT. The general focus of this research was to explore, in depth, teaching and learning experiences in the DT to determine how these three courses, individually and in synergy, contribute to learning engineering design. To respond to this broad query, the following research questions were posed:

- How do faculty, students, and industrial cooperators of the DT conceptualize design?
- What are the critical goals of design education, as seen by faculty, students, and industry cooperators of the DT?
- What are effective teaching and learning strategies in design education, as seen by the faculty, students, and industrial cooperators of the DT?
- To what extent do faculty, students, and industrial cooperators of the DT think the current design education structure is successful?
- To what extent do the DT courses, individually and as a trilogy, reflect elements of a comprehensive literature-based conceptual framework for design education? How can a comprehensive literature-based conceptual framework for design education be applied to improve the courses?

The methodology used to investigate these questions is described in Chapter 3.

Chapter 2:

Literature Review

Individual faculty members, departments, and entire engineering programs seeking to develop and enhance design education in the undergraduate curriculum are confronted with a well-established curriculum tradition oriented toward engineering sciences, as well as the complexity inherent in developing teaching and learning plans for engineering design education. A teaching and learning plan for engineering design must acknowledge the features of design that stand in contrast to features of the science-oriented curriculum. These include design's creative, open-ended, experiential, inductive, and integrative components. Acknowledging these differences will then also lead to course goals, learning theories, structural frameworks for courses and programs, pedagogical strategies, and assessment and evaluation methods that differ from the curriculum of engineering sciences.

The body of literature addressing curriculum features appropriate for engineering design is continually expanding as practitioners share perspectives, experiences, successes, and challenges with one another. From this body of literature, one can extract findings and themes related to the complex task of teaching design and learning design. These findings and themes facilitate the development of an overall conceptual framework for engineering design education for this research in the Department of Biosystems Engineering, Western Canadian University.

This chapter systematically reviews curriculum features as they relate to engineering design education. The chapter begins with a review of the societal influences calling for enhanced design education in the undergraduate engineering curriculum. Definitions of design and the desired outcomes of engineering design education are examined, followed by a discussion of learning theories compatible with a holistic view of engineering design education. Structural frameworks and pedagogical considerations for design courses and curricula are addressed, together with examples of other institutions' models of multi-course design experiences. Finally, assessment and evaluation in engineering design education is addressed. In each of these sections, the literature is both surveyed and then critiqued with a view to synthesize a position, understanding, or framework that can be applied to the current research. The individual understandings are then integrated into a more comprehensive framework for engineering design education, presented near the end of this chapter (Figure 2.9). A summary of commonly-used abbreviations is included as Appendix A.

Influences for Enhanced Design Education in the Engineering Curriculum

For a clearer understanding of the nature and scope of the momentum toward enhanced engineering design education, this chapter begins with a review of institutional bodies and societal influences that are instrumental in articulating the shortcomings of the current curriculum as well as in creating initiatives toward change. The influences that have shaped the undergraduate engineering curriculum to its current form and structure have their roots generally in the nature of professional education as institutionalized in universities and in the Positivist tradition of university education (Schön, 1983; Schulman, 1998). However, influences from directly within the engineering community have also shaped the curriculum to its current form, with greater emphasis on engineering theory or science over engineering practice or design, and a perceived lack of integration between the two areas. Specifically, the Grinter Report, published in 1955, is considered seminal in mandating and validating an engineering science emphasis in the curriculum (Harris et al., 1994).

This historical emphasis on engineering science in the undergraduate curriculum is coming under increasing pressure today. There have been multiple calls to better educate engineers in design by increasing its visibility in the curriculum and by fully integrating engineering design into the rest of the curriculum. While these voices have been heard since the late 1980s and increasingly throughout the 1990s, engineering faculties are only slowly moving toward these goals, perhaps in response to the now-united calls from diverse areas of the engineering communities, including practitioners, funding bodies, accrediting bodies, discrete industries and employers, and design-oriented faculty (Smith, 2000).

There is consensus in these voices that the divide between analysis and design in the undergraduate engineering curriculum is artificial and untenable. Dym (1999) reviews three concerns related to engineering education, one of which he calls the 'Analysis vs. Design' divide. This divide is characterized by design not being properly taught nor adequately presented in engineering curricula, and a resistance at the institutional level to incorporate more design into the curriculum. This resistance is attributed to the professional experiences of engineering faculty, which generally include extensive experience in teaching and in analysis, but minimal direct, personal experience doing design. Dym (1999) argues not for a wholesale replacement of analysis courses with design courses, but emphasizes that both design and analysis are essential for engineering learning and engineering practice. He argues for an "attitudinal paradigm shift" (p. 146) that recognizes design as being the heart of engineering, recognizes analysis for its centrality in formulating and modeling engineering problems and evaluating design results, and understands that students learn engineering science to enable them to do design.

Gibson (1995) likewise makes reference to the artificial divide between theory and practice (analysis and synthesis), claiming that it lacks a valid epistemological foundation. He eschews the practice that engineering design is often viewed as another routine, discrete subject heading rather than a synthesizing activity. This change in thinking has implications for how engineering is taught. Bucciarelli, Einstein, Terenzini, & Walser (2000) claim that the traditional educational ideology where knowledge is considered as some kind of material substance and good teaching as the efficient transmission of knowledge from a lecturing teacher to a passive student will no longer serve. Reform of engineering education, if it is to meet the challenge of today's professional needs, must open up the curriculum to enable active learning. They recommend the infusion of design and open-ended experiences throughout the curriculum as one means to achieve this goal.

Institutional Influences - Canadian

In Canada, a number of voices with both financial and legal influence on engineering education are challenging engineering faculties to increase and enhance design education. NSERC is one of three arm's length research granting agencies of the federal government, contributing $580 Million in 2001-2002 to research and training in engineering and natural sciences (Natural Sciences and Engineering Research Council, 2001). Even with a strong historical emphasis on basic research, NSERC introduced a 'Chairs in Design Engineering' program in 1999. Through the Chairs program, NSERC provides significant funding to universities for the establishment of up to sixteen Chairs in Design Engineering over a five-year period beginning in 2000. The Design Chairs are charged with guiding universities in meeting the demand for design engineering talent, creating and developing new designs, design concepts, and design tools. The stated motivation for this program is to enhance Canada's economic performance and productivity in a knowledge-based global economy and to address one of the stated major gaps: a shortage of people with skills and knowledge to make innovation happen, or a shortage of design engineers (Natural Sciences and Engineering Research Council, 2001b). The Faculty of Engineering at Western Canadian University was awarded an NSERC Design Chair in 2001.

While NSERC is one institutional voice with significant influence in engineering education, engineering programs are also responsive to the requirements of the national accrediting body. The role of the Canadian Engineering Accreditation Board (CEAB) is to accredit Canadian undergraduate engineering programs that meet or exceed educational standards acceptable for professional engineering registration in Canada. The CEAB operates as a standing committee of the Canadian Council of Professional Engineers (CCPE), which is national federation of the provincial and territorial associations that regulate the engineering profession in Canada and license the country's 157,000 professional engineers. The purpose of accreditation is stated to be, in part, an identification of those programs that "develop an individual's ability to use appropriate knowledge and information to convert, utilize, and manage resources optimally through effective analysis, interpretation, and decision-making. This ability is essential to the design process that characterizes the practice of engineering" (Canadian Council of Professional Engineers, no date, p. 9).

Article 2.2 of the CEAB Curriculum Content requirements for accreditation for the year ending June 30, 2000 state that "the entire [undergraduate] program must include a minimum of 1800 [Accreditation Units] AU". Within the 1800 AU, an engineering curriculum must include "a minimum of 900 AU of a combination of engineering sciences and engineering design. Within this combination, each of engineering sciences and engineering design must not be less than 225 AU". Article 2.2 further requires that "the engineering curriculum must culminate in a significant design experience" (Canadian Council of Professional Engineers, no date, pp. 11-13).

As a representative voice from outside the engineering community, Price Waterhouse (1996) completed a report for Human Resources Development Canada that was self-described as the first comprehensive study of the design sector in Canada to be undertaken at the national level. The purposes of the study were to build bridges among design disciplines (including engineering), to find models to effect change, and to strengthen the global performance of Canadian products, services, communications, and environments by good design. The authors assert that the performance of the design sector is intrinsically linked to the level and nature of a country's economic activity, and that the Canadian design sector has not realized its full potential as a catalyst for creating wealth. In looking forward to 2006, the report envisions, among other things, that design schools have significantly modified their curricula to reflect new demands, that effective bridges have been built between educators and practitioners of design disciplines, and that links between design education and practice have been strengthened.

Institutional Influences – American

Parallels to NSERC as the major funding agency for engineering in Canada and the CEAB as the national accrediting body for engineering programs in Canada can also be found in the United States. The (American) National Research Council (NRC) is the principal operating agency of the National Academy of Sciences and the National Academy of Engineering. The NRC exists to support research in sciences and engineering, as well to advise the US federal government. Currently, the NRC is seen as a strong supporter of strengthening engineering design education. It notes that the quality of engineering design in the US is poor and that best practices in engineering design are not widely used in US industry. The NRC further contends that improving the practice of engineering design in US firms is essential to industrial excellence and national competitiveness, and that industries, universities, and government all have a role to play in addressing this issue (National Research Council, 1991).

Specific shortcomings of the US engineering curriculum named by the NRC include a focus on selected conventional design procedures rather than on the entire product delivery process; lack of correlation between design education and the realities and scope of design practice; weak requirements for design content in engineering curricula; lack of truly interdisciplinary teams in design courses; fragmented, discipline-specific, uncoordinated teaching; lack of attention to state-of-the-art technologies; too few graduate programs focusing on modern design methodologies and research; limited funding for design research; rare involvement of industry experience; few faculty trained to teach design or cognizant of its importance; faculty with no significant industrial design experience and limited contacts with industry; lack of relevant textbooks; faculty lacking familiarity with instructional techniques that best support design education; and, institutional obstacles to faculty who would consider design as a career focus (National Research Council, 1991).

Partly in a response to this analysis, the Board of Engineering Education called for engineering educators to work together nationally to improve the engineering education system. This included a call for all institutions to pursue appropriate curriculum reform and to provide for more extensive exposure to creative design (National Research Council, 1995).

In addition to the initiatives of the NRC, The National Science Foundation (NSF), an independent US government agency, has developed an Engineering Design program as part of its agenda for promoting science and engineering by providing funds for research and education projects. The goals of the Engineering Design program are to enhance awareness of engineering design as an important element of engineering education and practice, to support research into the development of a discipline of engineering design, to encourage curriculum development to encompass modern concepts of engineering design principles, and to promote design education across the curriculum. The motivators for the program echo the NSERC Design Chairs program, claiming a need to improve and enhance design education as a direct vehicle toward economic competitiveness at a global level (National Science Foundation, no date).

Besides agencies that support research and provide funding, the national accreditation body for engineering programs in the US has also incorporated a more explicit emphasis on design requirements in the curriculum. As of June 30, 2001, the American Accreditation Board for Engineering and Technology (ABET) made a full transition to outcomes-based criteria for accreditation of undergraduate engineering programs. These criteria reflect the growing presence of design outcomes in engineering and include:

1. Each engineering program…must have in place (a) detailed educational objectives…; (b) a process…in which the objectives are determined and evaluated; (c) a curriculum and processes that ensure achievement of these objectives; (d) a system of ongoing evaluation that demonstrates achievement of these objectives and uses the results to improve…the program (Accreditation Board for Engineering and Technology, Inc., no date, p. 1).
2. Engineering programs must demonstrate that their graduates have (a) an ability to apply knowledge of mathematics, science, and engineering; (b) an ability to design and conduct experiments, as well as to analyze and interpret data; (c) an ability to design a system, component, or process to meet desired needs; (d) an ability to function on multi-disciplinary teams; …(Accreditation Board for Engineering and Technology, Inc. Criterion 3 (Program Outcomes and Assessment), no date, p. 1).
3. Students must be prepared for engineering practice through the curriculum culminating in a major design experience…incorporating engineering standards and realistic constraints that include…economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political (Accreditation Board for Engineering and Technology, Inc. Criterion 4 (Professional Component), no date, p. 2).

ABET's renewed emphasis on design pre-dates the shift to outcomes-based accreditation criteria, and Lovas & Packman (1996) indicate that the emphasis on design in the accreditation criteria have nonetheless failed to improve design significantly. Deficiencies in engineering design components of the curriculum are one of the leading causes of less than favourable accreditation actions by ABET.

Due to the difference in population of engineers between Canada and US and the high participation of Canadian engineers in American technical societies, curricula for engineering programs in Canadian institutions generally catch the momentum of trends originating in the US. (This statement, though, does not preclude the possibility of curricular trends originating in Canada, too). Thus, it is not surprising that engineering programs in both countries are charged with being overly science-oriented and are encouraged to enhance and develop design education to new extents. The general tenor of both the criticisms and the initiatives that have come forth from funding and granting agencies and accrediting bodies are comparable between Canada and the US. Due to the reliance of engineering programs on research funds from external research and granting agencies and due to the need for accreditation of engineering programs, these institutional influences become particularly powerful voices.

Together, Canada and the US have a sufficiently large population and an introspective disposition that combine to allow engineering programs to operate with a relatively high degree of isolation from engineering programs and trends originating in other parts of the developed world. Nonetheless, it is interesting to note that the push for change in the undergraduate curriculum crosses continental boundaries as well. Court (1998) discusses how the importance of engineering design within the UK industry has been a subject of extensive discussion for the past two decades. He claims an "essential need to provide an adequate supply of competent engineering designers in order for the UK industry to improve its competitive advantage" (p. 142). This perspective may not be universal, as Bender (2001) contends, "Germany (and most of continental Europe) has not gone through this extreme scientification of engineering education that the US experienced by misinterpreting the Grinter Report" (p. 336).

Industrial and Practitioner Influences

Outside of the influence of funding agencies and accrediting bodies, the views of industry (employers) and practicing engineers in Canada and the US highlight the need for improved design education in the undergraduate engineering curriculum. Nicolai (1998) claims that US industries are being beaten to the marketplace by foreign competition with a better quality product, due to a lack of engineering graduates with solid design experience. Lang et al. (1999) claim that although engineering practice continually evolves, engineering education has not changed appreciably since the 1950s, and that there exists a widening separation between faculty and curriculum and industry needs and expectations. This widening separation is designated a real threat to competitiveness in the global marketplace.

In an example of an industry-initiated program, Gorman et al. (2001) describe a program whose objective is "to influence the content of engineering education in ways that will better prepare tomorrow's graduates for the practice of engineering in a world-class industrial environment" (p. 143). The program takes a small number of competitively selected faculty from North American engineering schools and brings them into The Boeing Corporation for eight weeks to look over the shoulders of working engineers at various levels of technical and management careers. The authors go on to state,

> The message from our industrial partners conferring desired attributes of engineering graduates is very clear: a good grasp of engineering science fundamentals, a good understanding of design and manufacturing, good communication skills, curiosity and a desire to learn for life, and a profound understanding of the importance of teamwork (p. 145).

Proposed improvements for engineering education as developed by the faculty who participated in the program included: (relative to curriculum): adding more courses outside of traditional engineering disciplines; adding teaming to the curriculum for both faculty and students; focusing on the processes needed to solve problems; and, emphasizing process to the same extent as product. Proposed improvements relative to teaching style included more extensive use of design projects or open-ended problems, and proposed improvements relative to course synergy included developing a 'just-in-time' approach where topics are integrated within and between classes.

Lapins (1997) also refers to the current and future needs of the aerospace industry. He indicates that the aerospace engineering curriculum must examine not only the breath and depth of the technical curriculum, but also the adequacy and relevance of the student's design experience. Dutson et al. (1997) echo that many of the methods and objectives of academia are often considered to be different from those of industry, and Sheppard & Jenison (1997) refer to the influence of Boeing and other large corporations in their aggressive standards on what industry needs in future engineering graduates.

Davies, Csete, & Poon (1999) embark on a more conceptual discussion of the division of professional knowledge into the three domains of generic areas of knowledge (propositional knowledge as defined in curricula); generic skills (process knowledge); and, generic professional competencies. They state that the norms of higher education tend to favour scientific or propositional knowledge rather than professional competencies, where the knowledge base is likely to be couched in technical/scientific terms rather than practical terms. The practice knowledge required by employers is learned only through experience with practice. This separation between theory and practice is becoming increasingly recognized as a potential problem, and academic institutions are criticized generally for not providing the right graduates for industry.

Schulman (1998) claims that one of the sources of the tensions between theoretical and practical elements of professional education is the conflict between standards and conception of practice affirmed in the academy and those typically manifested in the field. However, contrary to popular views that criticize the conservatism of the academy, Schulman asserts that theoretical preparation tends to be more radical and reform oriented than the general tenor of practice itself. Academicians often see themselves as the critical conscience of professional practice, taking on the responsibility for criticizing current practice and developing a vision for the future. Schulman's discussion highlights that the discussion may not be as one-sided as the bulk of the literature suggests.

Apart from calls for change originating from a particular industry, professional associations for engineers likewise exert a pressure for improved engineering design education. Many professional associations for engineers are based in the US but inclusive of Canadian engineers as members, due largely to physical proximity and population differences between the two countries. The American Society of Mechanical Engineers (ASME), the Institute of Electrical and Electronics Engineers (IEEE), and the American Society of Civil Engineers (ASCE) have specific recommendations relative to including design in engineering education, as part of fulfilling the ABET criteria (Burton & White, 1999). Doepker (2001b) quotes from a keynote speech at the 1993 ASME Design Education Conference, stating "improving design methodology has been recognized as the single most essential step in industrial excellence and competitiveness" (p. 370).

Finally, Sheppard & Jenison (1997) and Sheppard (2001) highlight several other influences calling for increased and enhanced engineering design education. These include anticipation that more design education may be a means to decrease freshman attrition; student activism for curricular change; trends in student selection of majors; and, congruence between engineering design and the emergence of constructivism as a predominant educational theory.

Summary

The literature related to the influences on design education in engineering include calls for an increased design emphasis in the curriculum to balance the engineering science emphasis, an enhanced capability of faculty to understand and teach design effectively, and a synthesis of design and science in the curriculum. These proposed changes highlight the complementarity of science and design to expose students to the full essence of professional engineering. This shift in emphasis can be also seen to subsequently address the needs of industry for design talent and directly and indirectly enhance national competitiveness in a global economy. The calls for curriculum reform relative to engineering design come from institutional bodies including accreditation bodies (e.g. CEAB, ABET) and funding bodies (e.g. NSERC, NSF, NRC), and industry and individual practitioner voices, including technical societies (e.g. ASME, ASCE, IEEE), individual corporations (e.g. Boeing) and entire industries (e.g. aerospace). The convergence of these pressures for change has led to a resurgence of interest in design in engineering education, and the power of these influential bodies on the engineering curriculum has made the need for serious reflection and reconfiguration of the curriculum an urgent imperative for faculty and administrators.

Defining Design

Methodological Definitions

A fundamental challenge in developing design education and the beginning of any conceptual framework for design education is reaching a consensus on a definition of design. Due to the substantial financial influence of NSERC in engineering design education and engineering research in Canada, NSERC's definition or conceptualization of engineering design could be considered an important starting point for a definition to which academic programs should align themselves. NSERC (2001b) defines design engineering as concern

> [w]ith the design and development of new and improved products, processes and technologies that satisfy specified requirements in an effective and efficient manner. It includes the creation and development of innovative: tools, approaches, methodologies and standards to improve all aspects of product and

> process designs; and state-of-the-art designs of products, processes and process technologies. Design engineering is the enabler of innovation. It is the activity that creates the concepts and designs, and develops the new and improved products, processes and technologies that are needed in industry and in other sectors of the economy (p. 3).

Similarly, the CCPE (no date) publish a definition of engineering design against which engineering design education courses and programs are ostensibly evaluated during accreditation. Article 2.2.4 of accreditation criteria for engineering programs in Canada defines engineering design as follows:

> Engineering design integrates mathematics, basic sciences, engineering sciences and complementary studies in developing elements, systems and processes to meet specific needs. It is a creative, iterative and often open-ended process subject to constraints which may be governed by standards or legislation to varying degrees depending upon the discipline. These constraints may relate to economic, health, safety, environmental, social, or other pertinent factors (p. 12).

A number of authors have attempted to put forth a comprehensive definition that resonates with many of the elements proposed by NSERC and CCPE as components of engineering design. A general synthesis of these comprehensive definitions of engineering design includes

- A process of transformation
    - of ideas and knowledge
    - into a description, artifact, and/or detailed information available for further use, form, and/or function,

- carried out to satisfy a set of identified real or perceived needs or achieve stated objectives or function,
- taking into account set or negotiable constraints or specifications,
- in a systematic, intelligent process of generation and evaluation (Court, 1998; Sheppard & Jenison, 1997; Dym, 1994, 1994b; Reich, 1995; Smith, 2000; Campbell & Colbeck, 1998).

Koen (1985) succinctly summarizes these attributes by putting forth a definition of "the Engineering Method" (p. 5), in which designing embodies "the strategy for causing the best change in a poorly understood or uncertain situation within available resources" (p. 5). Zakis (1997) complements Koen by indicating that the techniques of engineering design are contrary to the scientific method and algorithmic approach to problem solving. The design paradigm is one of negotiable specifications and an unbounded set of initial solution concepts. From this perspective, engineering design may therefore be seen to be solution-based, as distinct from the problem-based approach of science and of research in the engineering sciences. The design process may be described as essentially visual, with a spatial, relational, global, and perceptual mode of thinking (as contrasted to a linear, sequential, logical, analytical, language-based process of analysis and research).

Eder (1997) further highlights that although problem-solving is one subset of skills required to engage in engineering design, problem-solving is not an adequate synonym to capture the complexity of engineering design. A large body of literature exists which expounds on the systematic, intelligent process of generation and evaluation, and in some cases appears to consider this methodology or process as singularly defining engineering design. Several of these definitions are reviewed in a later section entitled *Frameworks of Design.*

From outside of the engineering literature, Saxton & Miller (1996) articulate verbs that described the activities of students in the classroom, where those activities have a strong association or relationship with design and designing. These verbs are conceptualized into five families: creative; expressive; investigative; evaluative; and reasoning/thinking. The authors concluded that design teachers held the following 11 activities to be most important to student success or central activities of their [design] courses: planning; evaluating; modeling; communicating; expressing; experimenting; researching; making; recording; improving; creating. Despite the common elements in various definitions of design, this study also demonstrated a lack of shared understanding of meaning between teachers as to the nature of mentioned design activities.

Definitions based on Perspectives

Other authors show a preference for conceptualizing engineering design as something broader than a phenomenon than can be defined in one or two sentences. For example, Bucciarelli et al. (2000) take design to be more broadly conceived as "a perspective on, and an approach toward, engineering that can structure teaching across the curriculum" (p. 142). Design includes learning how to ask the right questions, deal with the ambiguity of the moment and uncertainty of the future, the ability to – given a task – to ferret out what is essential and what might be neglected, and the ability to effectively use available resources, to negotiate, to listen, and to explain. In a slightly different focus, Faste (2001) cautions that engineering designers must be prepared to think beyond the particular aspects of the design and consider more seriously the functionality of the design. Engineers must understand that when they design products for human use they are designing behaviours and experiences for users as well as providing functional utility or hardware. In this sense, designers have – perhaps unconsciously – the ability to shape cultural experience and values through the manifestation of the design.

Gibson (1995) likewise broadens the discussion beyond specific process, claiming that the activity of design encompasses a very wide perspective. It ranges from the highly practical in the form of model and prototype development to the obscurely theoretical in the forms of conceptualization and detailed scientific research. The end-results of design are experienced by everyone throughout their lives in the form of artifacts and in the characteristics of large organizations. While the range of design experiences may still resonate with the components of a definition stated earlier, Gibson (1995) highlights the difficulty of constraining design or limiting the environments or experiences that may constitute engineering design.

Another theme evident in the literature is the iterative or conversational character of engineering design, in that the end-point is ill-defined and that each step in the process only becomes clear as it is informed by the previous step. Wood (2001) articulates this aspect by defining design as the co-evolution of information and artifact. Moriarty (1994) discusses content and context as the two key components of engineering design, and the dynamic relationship between the two. Content is conceptualized as the elements of which the design exists, often advanced as standard definitions of engineering design. Context is conceptualized as the world within which the design exists and which conditions the design. Schön (1983) conceptualizes design as a reflective conversation with the materials of a situation, and dedicates an entire book to the discussion of design as a reflective conversation, or 'reflection-in-action', summarized as follows:

> A designer makes things. ... He [sic] works in a particular situation, uses particular materials, and employs a distinctive medium and language. Typically, his [sic] making process is complex. There are more variables – kinds of possible moves, norms, and interrelationships of these – than can be represented in a finite model. Because of this complexity, the designer's moves tend, happily or unhappily, to produces consequences other than those intended. When this happens, the designer may take account of the unintended changes he [sic] has made in the situation by forming new appreciations and understandings and by making new moves. He [sic] shapes the situation, in accordance with his [sic] initial appreciation of it, the situation 'talks back', and he [sic] responds to the situation's back-talk. In a good process of design, this conversation with the situation is reflective. In answer to the situation's back-talk, the designer reflects-in-action on the construction of the problem, the strategies of action, or the model of the phenomena, which have been implicit in his [sic] moves (pp. 78-79).

A Holistic Definition of Design

Existing literature on definitions of design suggests the need for a more holistic definition of design. This is particularly true when seeking a definition of design that provides a framework for the complex tasks of teaching and learning design. Any attempt at a holistic definition of engineering design needs to take into account both the methodological considerations that define design, as well as the considerations of perspective and approach that encompass design. To generate this proposed holistic definition of engineering design, the concepts of content and context are borrowed from Moriarty (1994) with liberties taken to conceptualize them further than explicitly articulated by Moriarty. In the graphical definition of engineering design shown in Figure 2.1, essential elements have been synthesized into a proposal for a holistic definition of engineering design.

The holistic definition is based upon a content of engineering design consolidated from the definitions of design put forth by various authors. This part of the design definition resembles a bounded phenomenon that can be further developed into a design methodology of linear or iterative elements. The second part of the holistic definition is the context of design, which encompasses the content. The context is comprised of the information relevant to the design (historical, social, economic, etc.), the perspective of design (reflective, creative, iterative, etc.), and the outcomes of design (hardware, concepts, behaviours, etc.). Circular arrows represent reflection, conversation, and iteration between the spheres of content and context in a definition of engineering design.

This holistic definition of engineering design forms an initial component of a comprehensive conceptual framework to inform engineering design education.

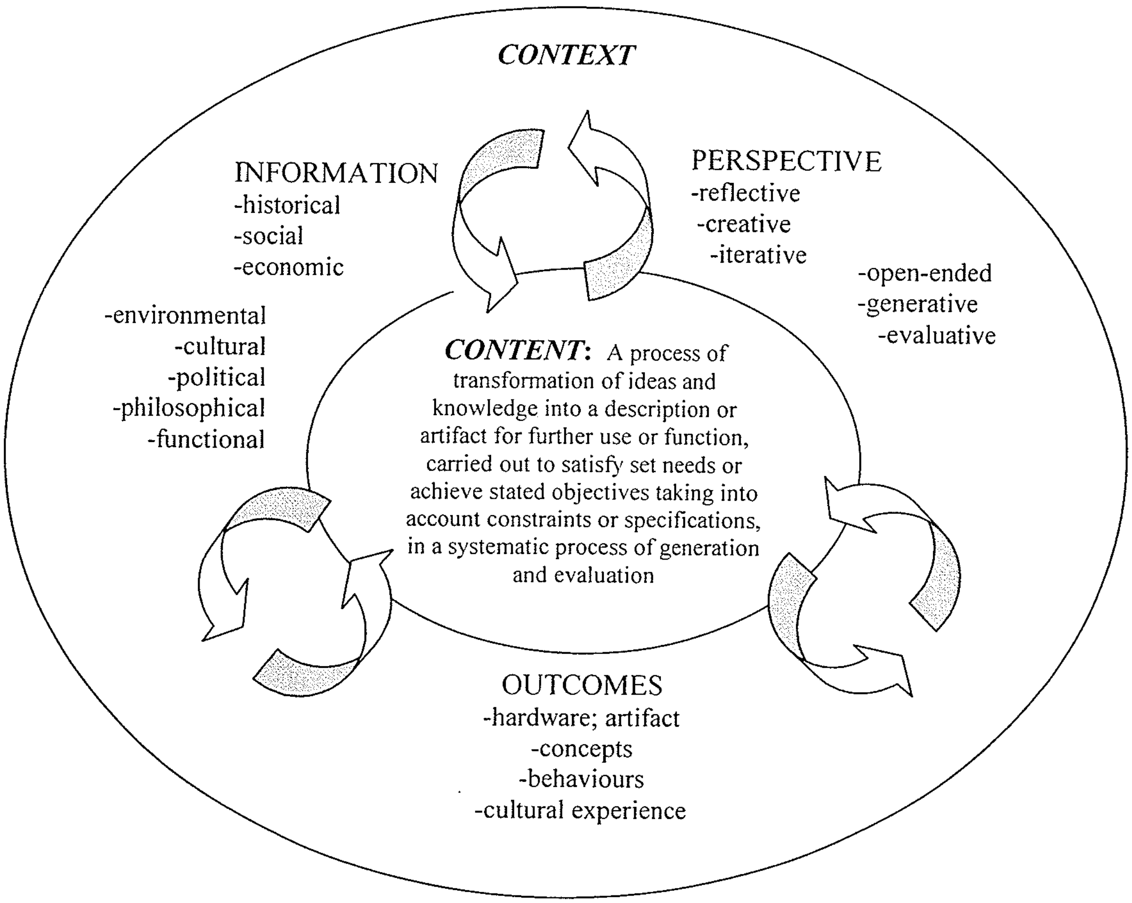


Figure 2.1: A Holistic Definition of Engineering Design

Desired Outcomes of Engineering Design Education

While a holistic definition of design is essential to begin a conceptualization of design education, the articulation of more specific skills and abilities are also critical to the development of effective design curricula. There is a high degree of congruence and repetition in the literature with respect to the desired attributes of design engineers. These attributes are at times framed as areas of knowledge, skill, and behaviour that engineers generally should possess and for which engineering design specifically is a suitable instructional vehicle. Alternately, these attributes are characterized as areas of knowledge, skill and behaviour that design engineers specifically should possess, and are stated as objectives of engineering design education. Regardless of the philosophical stance taken on design education, the learning outcomes are based in competent design practice and are similar between sources.

Eder (1999) proposes five general categories of competencies for design engineers, including heuristic competency (use of rules-of-thumb, intuitive guesses); branch-related competency; methods-related competency (synthesis, analysis, design, management methods); systems-related competency (input, output, transformation, operators, behaviour, properties); and social competency (societal awareness, cultural sensitivity, teamwork, interpersonal skills, communication skills, leadership, flexibility). Davies et al. (1999) discuss three broad domains of professional knowledge, which include generic areas of knowledge (propositional knowledge defined by curricula); generic skills (process knowledge); and generic professional competencies.

Eder (1999) and Davis et al. (1999) articulate the same ideas using different characterizations and breakdowns. Eder's (1999) categories remain grounded in the vocabulary of engineering, while the categories of Davies et al. (1999) lend themselves to broader, interdisciplinary dialogue. For the purpose of further discussion in this section, the three broad domains of professional knowledge by Davies et al. (1999) have been adopted. The categories of knowledge, skills, and professional competencies are well-articulated in terms of bridging the discussion from the outcomes of engineering design education to the later discussion of cognitive theories and definitions of learning.

Propositional Knowledge

The first domain of professional knowledge proposed by Davies et al. (1999) is prepositional knowledge. While much has been written on the overemphasis of engineering science in the undergraduate curriculum, there is strong agreement that a solid foundation in and understanding of engineering science fundamentals is requisite for designing (propositional knowledge defined by curricula). This includes an ability to apply knowledge of math, basic sciences, and engineering, and to model the physical world using the fundamental theories, methods, languages, and tools of an engineer (ABET, no date; Sheppard & Jenison, 1997; Kolar, Muraleetharan, Mooney, & Vieux, 2000; Lapins, 1997; Bucciarelli et al., 2000; Gorman et al., 2001; Regan, Dally, Cunniff, Zhang, & Schmidt, 2001).

Process Knowledge

Process knowledge in design and analysis is also identified as a required key competency. This includes the ability to design and conduct experiments, analyze and interpret data, and generally use analysis in support of synthesis (ABET, no date; Sheppard & Jenison, 1997; Linder & Flowers, 2001).

Furthermore, design skills are identified as a required competency, and exposure to adequate and solid design experience is identified as a key requirement. This includes the skill and ability to design a system, component, or process to meet desired needs. It also includes knowledge and practice of the engineering design and manufacturing processes (ABET, no date; Tsang et al., 2001; Kolar et al., 2000; Dutson et al., 1997; Lapins, 1997; Wilczynski & Douglas, 1995; Burton & White, 1999; Gorman et al., 2001; Regan et al., 2001; Knox et al., 1995).

In an attempt to articulate some of the sub-components of competency in design skills, the following specific required competencies have been identified: the abilities to

- Find information and use a variety of resources to construct a rational proposal (Sheppard & Jenison, 1997; Bucciarelli et al., 2000);
- Think with a multi-disciplinary systems orientation, considering integration and the needs of various facets of the problem in the problem-solving process (Sheppard & Jenison, 1997; Wilczynski & Douglas, 1995; Regan et al., 2001);
- Flexibly deal with, define, and/or formulate open-ended, under-defined, ill-defined, abstract, ambiguous, broad, and/or complex problems in environments of uncertainty, as a means to develop higher-level critical thinking skills in both an independent and a cooperative environment (Sheppard & Jenison, 1997; Bucciarelli et al., 2000; Wilczynski & Douglas, 1995; Kolar et al., 2000; Gorman et al., 2001; Campbell & Colbeck, 1998; Regan et al., 2001; Mackenzie, Allen, Earl, & Gilmour, 1999);

- Generate and evaluate creative problem solutions and alternatives (Sheppard & Jenison, 1997; Bucciarelli et al., 2000; Bender, 2001; Campbell & Colbeck, 1998);
- Recognize, identify and use a systematic, modern, step-by-step problem solving approach, including recognition of the need for iteration in design (Sheppard & Jenison, 1997; Lapins, 1997); and,
- Build up, troubleshoot, and test real hardware to prototype ideas (Sheppard & Jenison, 1997).

The knowledge and process skills comprise a very complex skill set, which is required for engineers to competently design. The implications for the design curricula include a need to blend knowledge transmission (construction) with experiential learning and an integration of content and process. Further implications are the need to re-evaluate structural components of the curriculum, such as artificial divisions between subject areas and courses, time allocation to subject areas and courses, sequencing within the curriculum, and scheduling structures. Finally, the complex skill set implies re-evaluation of the physical facilities in which learning occurs and the required pedagogical expertise or human resource strengths that facilitate students learning design.

Professional Competencies

Along with the succinct characterizations of required propositional knowledge and process knowledge, the literature presents a more extensive and diverse list of requisite generic professional competencies for design engineers. Frequently mentioned is the need for multi-disciplinary (and/or interdisciplinary and/or transdisciplinary) teamwork skills, including an understanding of, experience in, competency in, and commitment to function on teams in collaborative and active learning environments and solve problems in teams (ABET, no date; Sheppard & Jenison, 1997; Tsang et al. 2001; Knox et al., 1995; Kolar et al., 2000; Lapins, 1997; Bucciarelli et al., 2000; Burton & White, 1999; Gorman et al., 2001; Campbell & Colbeck, 1998; Court, 1998; Faste, 2001; Bender, 2001; Regan et al., 2001).

Another aspect of required professional competency is creative problem-solving. This has been summarized as the ability identify, formulate, and solve engineering problems using skills of critique, computation, creativity, intuition, spatial visualization, and holistic reasoning (ABET, no date; Sheppard & Jenison, 1997; Zakis, 1997; Gorman et al., 2001; Campbell & Colbeck, 1998; Court, 1998; Mackenzie et al., 1999).

The end result of problem-solving generally requires communication of some type, and communication skills have been further identified as a key professional competency. Communication skills encompass the ability to communicate, negotiate, and persuade, competency in using graphical and visual representations, effective skills in oral and written communication and presentation, and communication skills across disciplinary boundaries (ABET, no date, Tsang et al., 2001, Campbell & Colbeck, 1998; Sheppard & Jenison, 1997; Knox et al., 1995; Wilczynski & Douglas, 1995; Gorman et al., 2001; Court, 1998; Bender, 2001; Regan et al., 2001).

A fourth aspect of required professional competency is an understanding of professionalism, as well as professional and ethical identity and responsibility. This includes the foundation to engage in self-evaluation and reflection, a recognition of the appropriate role of code and regulation, and familiarity with the philosophical underpinnings of the culture and the profession (ABET, no date; Sheppard & Jenison, 1997; Wilczynski & Douglas, 1995; Bucciarelli et al., 2000; Gorman et al., 2001; Campbell & Colbeck, 1998; Faste, 2001). A sound professional and ethical understanding also requires contextual awareness as a professional competency. This refers to the breadth of view necessary to understand the impact of engineering in a global and societal context, the ability to consider various non-technical forces acting on a problem (economic, social, environmental, etc.), an appreciation of different cultures and business practices, an awareness of global community including the social and cultural meanings of designed products, and a knowledge of contemporary issues (ABET, no date; Sheppard & Jenison, 1997; Tsang et al., 2001; Bucciarelli et al., 2000; Gorman et al., 2001; Campbell & Colbeck, 1998; Faste, 2001; Bender, 2001; Regan et al, 2001).

Additionally related to a sound sense of professionalism is the requirement to understand the need for life-long learning. This required professional competency includes a foundational recognition of the need for and ability to engage in life-long learning, an ability to identify critical technology and approaches and to stay abreast of change in professional practice. This has been summarized as a continuous learning orientation (ABET, no date; Sheppard & Jenison, 1997; Wilczynski & Douglas, 1995; Bucciarelli et al., 2000; Gorman et al., 2001; Faste, 2001).

Practical skills have been identified as a fifth requisite professional competency. Practical skills include an ability to use a variety of resources - techniques, skills, and tools of engineering practice – and to judge which tools are appropriate for each task. This aspect also refers to practical experience in workshop skills specific to the particular engineering discipline (ABET, no date; Bucciarelli et al., 2000; Burton & White, 1999; Mackenzie et al., 1999).

Finally, relatively fewer authors put forth additional requisite professional competencies that may be facilitated or enhanced by design education. These include the development of leadership qualities and management skills (Tsang et al., 2001, Zakis, 1997; Wilczynski & Douglas, 1995; Bender, 2001), and an understanding and appreciation of the diversity of students, faculty and staff (Tsang et al., 2001).

At times, these professional competencies have been called the 'soft skills' of engineering. Strategies at developing soft skills in students have included requiring a minimal amount of credit hours in the curriculum to be taken in elective courses outside of engineering or offering the same types of non-engineering elective courses as service courses to cohorts of engineering students. The professional competencies, though, relate directly to the practice of engineering and the practice of design, and thus should not be separated from the experience of learning the associated knowledge and skill components. Maximum understanding, retention, and appropriate application of these professional competencies or 'soft skills' will be achieved when they are learned and practiced in realistic contexts. Furthermore, the required professional competencies imply a curriculum that allows for a substantial amount of student-student and student-faculty interaction, multiple opportunities to demonstrate learning and improvement, and grappling with realistic problems in realistic contexts.

Design as Discipline Knowledge

It is interesting to note that many desired outcomes of engineering design education are not discipline-unique (to either engineering or to design). Besides the desired discipline-knowledge outcomes, the desired behavioural and developmental outcomes of engineering design education can be roughly summarized as Dressel & Marcus' (1982) "six humanizing competencies" (p. 46) of an educated person, including:

(1) An ability to acquire knowledge and use it;

(2) A high level of mastery of the skills of communication;

(3) An awareness of his or her own values and value commitments, and a realization that other individuals and cultures hold contrasting values that must be understood and, to some extent, accepted in interaction;

(4) An ability to cooperate and collaborate with others in studying, analyzing, and formulating solutions to problems and taking action on them;

(5) An awareness of, concern for, and a sense of responsibility about contemporary issues, events, and problems; and,

(6) An ability to relate his or her development of competencies into a coherent, cumulative, and somehow unified experience and to apply these competencies to further development as an individual and to the fulfillment of obligations as a responsible citizen in a democratic society.

Furthermore, the desired cognitive outcomes of engineering design education may also be articulated within Dressel & Marcus' (1982) conceptualization of foundational knowledge in a discipline as five components. These components can be summarized as:

(1) Substantive component: the subject matter of the discipline, or problems of interest to the discipline. This includes, for example, bodies of previously acquired and organized knowledge, basic or fundamental facts, concepts, principles, and processes;

(2) Linguistic component: the symbology or modes of representation (language system) by which elements can be identified and relationship defined and explored. These language or symbolic structural components facilitate and direct thought in a discipline;

(3) Syntactical component: a set of search and organizing processes around which the discipline develops, or the disciplinary principles, procedures, skills, and assumptions or limitations that define a field and mode of inquiry within the field;

(4) Value component: value commitments about what is worth studying and how it should be studied; and,

(5) Conjunctive component: the way in which a discipline is related to other disciplines.

Dressel & Marcus (1982) claim that no teacher can fully understand or apply – or presumably facilitate learning within – a discipline without some grasp of these five components that are embedded in each discipline. These five components markedly influence the nature of the discipline as well as its further development.

Dressel & Marcus' (1982) framework provides a way for engineering design faculty to understand the complex task of facilitating learning of design in terminology broader than the terminology of engineering. In addition, it allows faculty to recognize that other disciplines and professions also have faced this complexity, and the body of literature that can inform the task extends beyond engineering boundaries. Finally, engineering design faculty can use Dressel & Marcus' (1982) framework as a framework for self-reflection – to assess how one's own understanding and priorization of the five components of foundational knowledge in a discipline (whether engineering science or engineering design) informs one's teaching of the discipline. Such self-reflection and subsequent self-knowledge may be a necessary precursor to attempts to authentically work with a design paradigm (vs. a science paradigm).

Engineering Design in Relation to Learning Theory

The classification of generic areas of knowledge (propositional), generic skills (process), and generic professional competencies proposed by Davies et al. (1999) also resonate with (although do not parallel) Fincher's (1998) broad definition of learning as a process of progressive change from ignorance to knowledge, from inability to competence, and from indifference to understanding. The three goals and the respective outcome classifications of these three domains are conceptual learning or knowledge goals as a cognitive outcome, skills learning as a behavioural outcome, and values learning as a developmental outcome. Fincher (1998) denotes this as an attempt to synthesize cognitive, behavioural, and experiential concepts into a provisional "three-level, multiple-stage 'schema' for learning" (p. 76). Although the implication exists in this characterization, Fincher's definitive position on a hierarchy between the three levels remains unclear.

Fincher's schema can be used to organize the desired outcomes of engineering design education cited in literature. This proposal is summarized in Figure 2.2.

Cognitive Outcomes: **Knowledge & Conceptual Learning**	*Behavioural Outcomes:* **Skills and Competencies**	*Developmental Outcomes*: **Values and Perspectives**
Engineering science fundamentals: mathematics; basic sciences	Design skills	Multi-disciplinary team orientation
Engineering theories, methods, systems, languages, and conceptual tools	Analysis in support of synthesis	Professional and ethical identity
Design process	Creative problem-solving; holistic reasoning; heuristics	Contextual, cultural, and global awareness
	Professional and personal communication	Continuous learning orientation
	Practical skills	Leadership

Figure 2.2: Desired Outcomes of Engineering Design Education

A brief examination of learning theory is useful in understanding the connections between Fincher's schema and the relationships between the structure of design knowledge and the structure of design education.

Behaviourist Theories

The literature reveals diversity of thought with respect to a learning or developmental theory that lends itself to effective teaching and learning of engineering design at the undergraduate level. On the one hand, Koen (1994) proposes that design must be viewed as a behaviour, and that to teach design effectively involves the principles of Behaviourism, as conceptualized by theorist B.F. Skinner. Koen (1994) articulates his thesis in four parts, stating that (1) design is behaviour; (2) teaching design is changing behaviour; (3) behaviour modification is the most appropriate way to teach design; and, (4) engineering heuristics are the behaviours we want to achieve. Koen

(1985) defines heuristics as rules of thumb, intuition, technique, rule of craft, or engineering judgment. Sample heuristics include ‘the yield strength of a material is equal to a 0.02% offset on the stress-strain curve’ (rule of thumb), ‘always give an answer’ (attitude heuristic), ‘make small changes to the state-of-the-art’ (risk-control heuristic), and ‘allocate resources as long as the cost of not knowing exceeds the cost of finding out’ (resource allocation heuristic).

In summarized form, the fundamental premises of Skinner’s psychology are that humans are active; they emit behaviours of various kinds. When a behaviour is emitted, it has consequences that may affect the future of the behaviour. These consequences may either increase or decrease the likelihood that the behaviour will occur again. The consequences are determined by the organism’s social and physical environments. Consequences that are expected to increase the likelihood that the behaviour will occur again include positive reinforcement (adding something positive to the environment in response to the behaviour) and negative reinforcement (removing something negative from the environment in response to the behaviour). Consequences that decrease the likelihood that the behaviour will occur again include punishments (removing something positive or adding something negative to the environment in response to the behaviour) (Nye, 1992). In essence, behaviourist theories relate human behaviour and achievement to a response to external stimuli, and Skinner’s program for controlling behaviour rests on the use of positive reinforcement (Zuber-Skerritt, 1992; Nye, 1992).

Skinner’s conceptualization of behaviourism has been criticized on numerous counts. It is charged with being too simplistic and failing to account for the internal worlds and richness of human beings in causing or directing their own behaviour.

Common reasons for criticism of behaviourism include an alleged contradiction with the Western ideal of self-determination and behaviourism's perceived negation or lack of validation of concepts of free choice, personal responsibility, and individualism in directing behaviour. Second, behaviourism is criticized for its emphasis on the concept of control, and the extent to which it views the individual as being controlled by one's environment (genetic endowment, past history of personal experiences, and present environmental conditions). Third, behaviourism is criticized for basing its suggestions relative to human behaviour on research conducted on lower animals. Finally, and relevant to a discussion on engineering design education, behaviourism is criticized for being too mechanistic, simplistic, and generally inappropriate as a credible theory for application to complex behaviours such as those displayed in critical thinking and creative activities (Nye, 1992; Zuber-Skerritt, 1992).

A more recent criticism of behaviourism reflects on the need to study variables in context in order to enhance the validity of findings and generalizations. Psychology scholar Egon Brunswick and his later advocates focused on the notion that mental activity depends on both the organism and its social and physical environment, and that the contexts in which thinking takes place are crucial to the outcomes of thought (Bower, 2002).

Todd & Morris (1995) and Nye (1992) assert that many of behaviorism's premises have been misinterpreted – interpreted too simplistically or not fully understood. They go to some detail to broaden the discussion and reexamine the dimensions of criticism, although the criticisms are not entirely extinguished. Behaviourism does rest on a conception of the environment as the prime influence directing human behaviour. Although Skinner acknowledged the importance of feelings and thoughts, he did not see them as having any causal status in his system of psychology. Relative to creativity, Skinner does discuss it and again his reasoning remains grounded in environmental influence. Skinner's behaviourism does not account for creativity by referring to 'creative impulses' or 'inner resources', but rather creativity is the result of a person's genetic endowment and complex history of environmental reinforcements for a wide variety of behaviours (Nye, 1992).

In general, behaviourism is present to some extent in most teaching and learning environments. Nonetheless, it remains criticized for neglecting the humanist and interactionist elements of learning that give responsibility and choice to the learner and that allow learner control and motivation to influence the learning outcomes. Since Skinner's version of behaviourism is known to be widely criticized and allegedly widely misunderstood, it is also difficult to assess Koen's (1994) specific perception or conception of behaviourism for which he advocates in engineering design education.

Koen's (1994) perspective, whether advocating simplistic or more complex behaviourism, is nonetheless evaluated to be inappropriately narrow for the post-secondary environment. Taking into account Skinner's comments on creativity, Koen's (1994) contribution is in encouraging educators not to dismiss the creative aspect of design as 'un-teachable', but rather to investigate the behaviours that one normally identifies as components of creativity and search for ways to allow students to rehearse and receive reinforcement in the use of these behaviours.

Experiential and Cognitive Theories

Behaviourism as an appropriate learning theory for engineering design is not reflected widely in the literature. Most authors tend toward either an experiential or a cognitive view of engineering design. Dym (1994; 1994b; 1999) summarizes three schools of thought in American engineering schools about teaching and learning design. The traditional view is that design is *experiential* in nature and creativity cannot be taught. Any attempt to formalize and articulate a scientific theory of design will lead to the ruin of engineering design education. The second view is that no meaningful discipline of design can emerge until it can be put into *mathematical* terms. This school of thought also argues that there is, as yet, no real content to design education, as traditional design teachers have not been able to successfully articulate the intellectual content of their courses. The third and emerging school of thought of the last decade argues the need for a more scientific approach to the study of design and the need for a much broader view of design that is embedded in the notion that design is a *cognitive* activity that can be studied by cognitive scientists. This view sees design as its own discipline with its own structure, methods, and vocabulary for both the process and the designed objects. In the cognitive view, design is a legitimate area of intellectual inquiry.

At least in terminology, Gorman, Richards, Scherer, & Kagiwada (1995) blend the experiential and cognitive schools of thought by contrasting experiential cognition with reflective cognition. An expert working in a familiar domain can operate largely on pattern recognition and does not need to reflect, manifesting experiential cognition. The obvious solution emerges from experience. An expert in a domain moving into a new domain, in which prior experience does not produce a solution, will be more likely to manifest reflective cognition. Under novel conditions, a designer will have to reflect on problem-solving strategies and ways of representing the problem, in order to come up with a new way of reaching a goal.

Most students will be in a reflective cognition stage and consequently design education must be structured to create opportunities for reflective cognition. For example, Tsang et al. (2001) propose service learning as an appropriate means of experiential education to teach design. Service learning is defined as a form of experiential education in which students engage in activities that address human and community needs together with structured opportunities intentionally designed to promote student learning and development. Key concepts of service learning include reflection and reciprocity. Service learning is asserted as an appropriate framework from which to teach design, given that design is argued to be at the heart of engineering and that furthermore, any definition of engineering would include 'service to society' as a mission of the profession. Tsang et al. (2001) argue that in carrying out a service-learning design project, students enhance the development of soft skills required in ABET Engineering Criteria 2000 (EC2000) in addition to their technical capabilities, and that service learning provides an ideal context for engineering undergraduates to learn and practice design.

Tsang (2000) proposes the Kolb Learning Cycle as an appropriate learning model on which to base design education. This model, conceived around 1980, is also experiential in nature, exposing students iteratively to activities along two dimensions of 'input' and 'processing'. Students are guided through a complete learning cycle of concrete experience (input), followed by reflective observation (processing), followed by abstract conceptualization (input), followed by active experimentation (processing), which ultimately leads to another concrete experience (Kolb, 1998). Tsang (2000) argues for the Kolb Learning Cycle as an effective framework to learn high-level analysis, synthesis, and evaluative skills. He further argues for the Kolb Learning Cycle as an effective means to give students the opportunity to experiment on their own, be given rapid, accurate feedback on their performance, and be given multiple opportunities to develop and master their skills. In this sense, the Kolb Learning Cycle provides a formalized experiential structure for design education that goes beyond the traditional experiential school of thought described by Dym (1994; 1994b; 1999).

Using different wording but seemingly getting at the same root ideas of experiential learning based on or congruent with current cognitive theory, Sheppard & Jenison (1997) contend that design education, when based on open-ended problem solving and authentic projects is consistent with the Constructivist school of thought and learning theories currently held by cognitive scientists. Constructivism is defined as a theory that sees knowledge as constructed from experience rather than transmitted to students as if they were empty vessels to be filled. In Constructivism, learning results from a personal interpretation and learning is active, with meanings developed on the basis of experiences (which include engagement with discipline knowledge). Furthermore, learning is collaborative with meanings negotiated from multiple perspectives, and learning should be situated in realistic contexts.

Schulman (1998), writing from outside of the engineering context, discusses cognitive scientists' increasing interest in the idea of apprenticeship with renewed respect for the apparent educational potency of apprenticeship models. He maintains that the idea of a 'cognitive apprenticeship' has taken hold. This idea criticizes academic settings for separating theoretical knowledge from practical applications and for teaching complex processes far from the situations in which they are used. An effective apprenticeship model teaches the practical, judgmental, and situated intellectual work that characterizes traditional crafts and occupations, with the reflective and elaborative mechanisms that characterize higher-order thinking. It achieves these daunting goals by embedding the learning in the social context of practice, permitting the apprentice to move from observation to limited participation to full responsibility slowly and with serious modeling and supervision.

The discussion highlights the range of available learning theories around which a course, a teaching strategy, or an entire curriculum can be organized. It also highlights the need to critically analyze the multiple dimensions of engineering design education and align each dimension with an appropriate learning theory. The end result, though, must be an overall learning theory of congruent pieces, rather than multiple theories that operate in conflict with one another. Such an analysis and synthesis of cognitive and experiential learning theories for engineering design are described in the *Summary* to this section.

Other Theories

Finally, and more difficult to categorize, are the attempts of various authors to draw parallels between the very nature or structure of design and the nature or structure of teaching and learning processes and organizational characteristics (see, for example, the *Assessment and Evaluation in Engineering Design Education* section in this literature review for a parallel between design and assessment theory). In this manner, Eder (1994) discusses learning theories as they relate to teaching and learning in engineering education. He summarizes several learning theories and explores relationships and comparisons between learning theories, product development and design, and the progress of science. He likens a product life to human development as per Piaget, engineering design to formal education as per Perry, problem solving in design to problem solving in teaching and learning as per Kolb, and design ability and creativity to cognitive styles.

These comparisons highlight that although engineering design and learning theory are very different areas of knowledge and expertise, conceptual parallels may exist. These conceptual parallels can assist engineering design faculty in understanding and evaluating an appropriate learning theory for engineering design. However, in the following discussion that culminates in a proposal at an appropriate learning theory for engineering design, the comparisons articulated by Eder (1994) have not been applied directly.

Summary

The holistic definition proposed for engineering design is both multi-dimensional (content and context) as well as conversational or reflective between the two dimensions. Furthermore, the desired outcomes for students of engineering design education are defined along multiple dimensions, including cognitive outcomes (knowledge), behavioural outcomes (skill competencies), and developmental outcomes (values and perspectives). A learning theory for engineering design needs to acknowledge these multiple dimensions. Therefore, an appropriate learning theory for engineering design may evolve as a synthesis of learning theories and orientations that provide the capacity to address the complex task of engineering design education.

In agreement with current thinking about the nature of design, a learning theory for design education needs to include a cognitive dimension. As Dym (1994; 1994b; 1999) articulates, a view of design as a cognitive activity includes a view of design as its own discipline with its own structure and methods. The concepts of a unique and identifiable discipline structure and methodology become powerful when advocating for legitimacy of the alleged 'soft' design curriculum within the traditional 'hard' engineering curriculum. Aligning a cognitive learning theory with design education can facilitate this acceptance within the institution and provide conceptual bridges to existing engineering science curricula.

Cognitive psychology focuses on the human mind: its memory, its cognitive structures, and processes of information storage, retrieval, and use. Cognitive structures are generally defined as knowledge stored in the brain in an organized way such as a conceptual hierarchy, where minor elements of knowledge are subsumed under larger, more general, more inclusive concepts. A cognitive structure may be envisioned as the brain's organizational chart of knowledge: the chart indicates every piece of knowledge and its relationship (hierarchy or otherwise) to other pieces of knowledge and to the conditions under which it is used. Cognitive psychologists claim that in the development of cognitive structures, some knowledge is inherited, new knowledge is continually added, and that existing knowledge is continuously changed in order to master the problems of the environment. Furthermore, it is generally thought that one's existing cognitive structure is the principal factor influencing meaningful learning and retention.

Logically meaningful material can only be learned in relation to previously learned material of relevant concepts, principles, and information that make possible the emergence of new meanings and enhance their retention and future application (Zuber-Skerritt, 1992).

Piaget's ideas also provide a foundation for understanding cognition. Three essential axioms of Piaget's theory are that (1) knowing is ultimately based on activity, both physical and mental, through interaction between self and environment; (2) development is a gradual and progressive reorganization of mental structures used to 'make sense' of the world; and, (3) learning occurs when the learner acts to resolve discrepancies between beliefs and the new information which does not fit those beliefs (Kurfiss, 1998).

While Piaget is criticized for focusing only on skills and tasks associated with the natural sciences and mathematics, the three axioms provide the springboard for interactionist, active, and progressive (i.e. staged) learning. An experiential model is considered an appropriate complement to a cognitive learning theory, in order to explicitly address the need to cyclically expose students to new information to develop their cognitive structures and to ground engineering design education in a learning theory that acknowledges context, interaction and engagement with the context, collaboration, and reflection.

The Kolb Learning Cycle is an experiential learning model representing an integration of research on cognitive development and cognitive style. The model is argued to be consistent with the structure of human cognition and the stages of human growth and development, while simultaneously emphasizing the important role that experience plays in the learning process (Kolb, 1998). In general, the Kolb Learning Cycle is well established and widely applicable across disciplines, including professional curricula (Svinicki & Dixon, 1998). Perhaps its strongest characteristic is the integration of theory and practice. The core of the learning cycle is a description of how experience is translated into concepts, and how concepts are, in turn, used to guide the choice of new experiences.

Learning is conceived as a four-stage cycle. Immediate concrete experience is the basis for observation and reflection. An individual uses these observations to build an idea, generalization, or 'theory' from which new implications for actions can be deduced. These implications of hypotheses serve as guides in acting to create new experiences. The four abilities needed by the learner are concrete experience (CE), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE) (See Figure 2.3). These four abilities occur along two primary dimensions of cognitive growth and learning: the concrete-abstract dimension, and the active-reflective dimension (Kolb, 1998).

McKeachie (1998) claims that the applications of cognitive psychology have provided bases for understanding the superiority of active processing of material over passive reception, as well as an account of how problem solving occurs in different disciplines. The Kolb Learning Cycle provides a formalized experiential framework in which to apply cognitive principles toward the desired learning outcomes of engineering design education. In addition, the Kolb Learning Cycle provides an ideal setting in which to apply apprenticeship or mastery concepts of learning, allowing students multiple opportunities at tasks for increased understanding, knowledge, and experience by repeating the cycle. Finally, the Kolb Learning Cycle is deemed to be flexible enough to engage a holistic definition of engineering design and to address cognitive, behavioural, and development outcomes of engineering design education in one credible learning model.

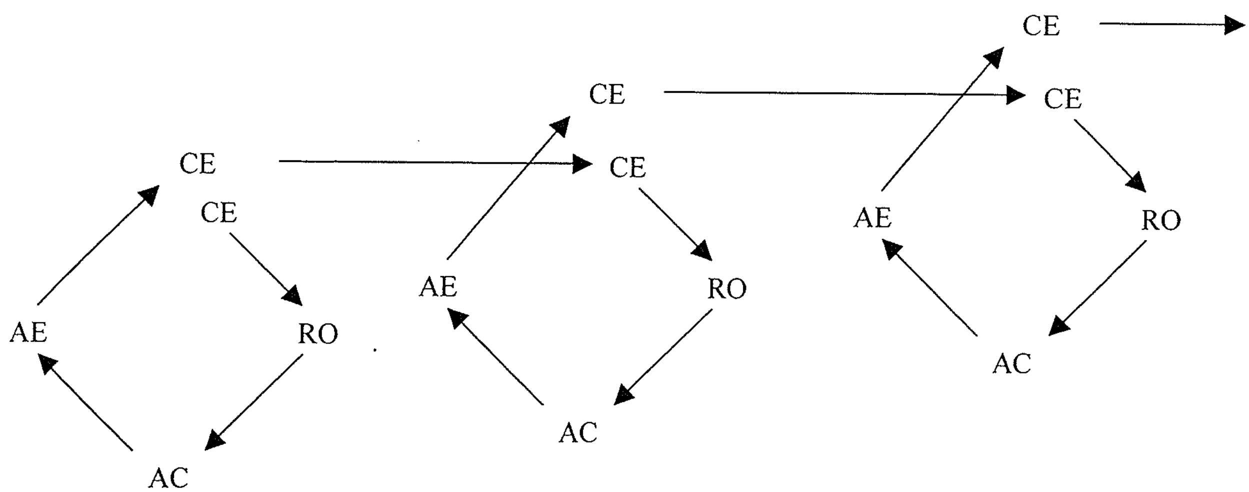


Figure 2.3: A Learning Model for Engineering Design Education: The Kolb Learning Cycle in an Apprenticeship (Mastery) model

Structural Frameworks

Frameworks for Design Education Courses and Curricula

The literature provides a strong research base from which to develop a holistic design definition and from which to synthesize desired learning outcomes and an appropriate learning theory for engineering design education. Despite this strong research base to support design education, only one reference was located in the literature that makes explicit reference to a structural framework for engineering design courses, and in which development and discussion of the framework are the primary objectives of the article. In two companion papers, Sheppard & Jenison (1997; 1997b) propose that the spectrum of possible design experiences that can be designed for freshman engineering students may be situated within a framework of two dimensions of (1) pedagogy and (2) structural differences. The horizontal dimension is the skill / knowledge type and it relates to the extent that the course is focusing on domain specific content and skills (one extreme of the continuum) or design qualities (other extreme of the continuum). The vertical dimension is the pedagogical approach and it relates to how the 'what' is taught, ranging from an individual orientation to a team-based orientation as reflected in the sum of the nature of homework assignments, use of class time, and how the work is assessed.

Sheppard & Jenison (1997; 1997b) further propose that the overlay of the vertical and horizontal dimensions define four distinct quadrants, one of which will characterize most existing engineering design course models. The four quadrants of the framework for design education are described as

(a) Individual-content centric, i.e. a traditional lecture-based course;

(b) Team-content centric, i.e. a traditional lab-based course;

(c) Individual-process centric, i.e. a studio art course; and

(d) Team-process centric, i.e. a capstone design course.

The framework proposed by Sheppard & Jenison (1997; 1997b) addresses the 'how' dimension of engineering design education – that is, how engineering design education may be structured. Other authors propose and discuss what also amount to 'how'-dimensional frameworks for engineering design courses without explicitly naming them as such. In addition, some frameworks are more comprehensive than others, addressing a wider or narrower range of the environment for teaching and learning engineering design.

Kuhn (2001) develops a framework of studio pedagogy, mentioned above as an individual-process centric model, and proposes it as an appropriate model for engineering design education. Kuhn (2001) characterizes studio pedagogy by seven attributes:

(1) Student work is organized primarily into semester-length projects, responding to a complex and open-ended assignment;

(2) Students' design solutions undergo multiple and rapid iterations;

(3) Critique is frequent and occurs in both formal and informal ways, from faculty, peers, and visiting experts; one of the hallmarks of studio education is the creation of a 'culture of critique';

(4) Heterogeneous issues – ranging from structural integrity to the social impact of the design – are considered, often in the same conversation;

(5) Students study precedents (past designs) and are encouraged to think about the big picture;

(6) Faculty help students to impose appropriate constraints on their design process in order to navigate a complex and open-ended problem and find a satisfactory design solution; and,

(7) The appropriate use of a variety of design media over the course of the project significantly supports and improves students' insights and designs.

These features of studio pedagogy also coincide closely with the description of design as a reflective conversation, or reflection-in-action, as described by Schön (1983). In another example, Marin, Armstrong, & Kays (1999) describe the capstone design program implemented at the US Military Academy at West Point, from which a framework for teaching and learning in the capstone course emerges. The framework addresses three areas:

(1) Preparation;

a. Student preparation – considering a 'crawl, walk, run' metaphor, in which students use engineering science courses to 'crawl', design integration in the curriculum to 'walk', and capstone design to 'run'.

b. Project selection – must be seen as worthwhile by students, faculty, and the industry whom it serves;

c. Instructor mentorship – inspiring students to take ownership, fostering creative tension, and giving students the opportunities to fail as well as succeed.

(2) Administration and execution; and,

(3) Assessment.

In a third example of a partial 'how' framework for engineering courses, Wesner (2001) summarizes the key learnings and commitments from the Mudd Design Workshop II (part of a conference 'Designing Design Education for the 21st Century', 19-21 May 1999). Five key commitments were identified:

(1) Focus on learning rather than teaching; use coaching rather than teaching as the methodology of the educator;

(2) Give attention to the humanities / humanistic engineer; include culture, values, and the notion of intent in the academic program;

(3) Include assessment and continuous improvement in the program;

(4) Focus on projects and experiential design learning; good design projects must be designed themselves; and,

(5) Grading and learning must be addressed in new ways.

Fronczak (2001) discusses design education and, in contrast to the above, allows the reader to extrapolate a 'what' framework for design education – that is, what design education should be addressing in the teaching and learning process. Fronczak (2001) defines engineering design as a complex process that requires knowledge, skill, and attitude. He argues that we have developed effective and efficient means of passing on knowledge, yet that skill and attitude are fundamentally different from knowledge and require a substantially different approach to educating the students. While knowledge may be taught, skill must be developed, and attitude must be cultivated and nurtured. Fronczak (2001) proposes three 'what' components for design education to address:

(1) Engineering practice, as based upon technology-based knowledge that is likewise based upon experience. This includes hardware or products,

techniques or processes by which these products are made, and the complete systems involved in the production of hardware;

(2) Skill, as the exercise of judgment, and judgment requires the wisdom of experience developed though good coaching, prompt and appropriate feedback, and multiple opportunities; and,

(3) Sound attitudes, including confidence, desire to venture into new uncharted territory, risk-taking, willingness to accept failure as a real possible outcome.

Finally, Bender (2001) allows the reader to extrapolate both a 'how' framework as well as a 'what' framework for design education from his discussion on purposeful and motivational teaching and learning in engineering design courses. He contends that the intentional dimensions of engineering design courses are the defined teaching objectives. In his discussion, the outcome is a "qualification scheme consisting of the 'five pillars' " (p. 337) of global teaching objectives and competencies for engineering design education:

(1) Subject-specific competencies, such as foundational technical knowledge;

(2) Methodological competencies, such as design and project management methods;

(3) Systems competencies, such as interdisciplinary thinking;

(4) Personal and social competencies, such as creativity, service orientation, and teamwork abilities; and,

(5) Practice competencies, such as project practice, design practice, and professional practice.

Bender (2001) uses the five proposed teaching objectives to further theorize that teaching and learning concepts for engineering design courses must encompass four dimensions: teaching objectives, teaching topics, teaching methods, and teaching media. He further synthesizes the proposed global teaching objectives and the teaching and learning dimensions by proposing the Kolb cycle of experiential learning as a suitable didactical (pedagogical) model for engineering design courses.

Other Frameworks

Besides structural frameworks that address the teaching and learning process for engineering design courses or curricula, other frameworks may also be discerned for individual components of a teaching and learning environment. For example, Fruchter (2001) proposes a framework for "teamwork education" (p. 426). In describing an architecture / engineering / construction education program launched at Stanford university in the early 1990s, Fruchter presents dimensions of teamwork education that include:

(1) A teaching and learning methodology that is problem-based, project organized, product-oriented, process-based, and people-based;

(2) Participants, including faculty, practitioners, and students from different disciplines;

(3) Content;

(4) Project;

(5) Information technology;

(6) Interactions; and,

(7) Assessment.

Finally, Linder & Flowers (2001) propose a framework for teaching for integration of engineering science and engineering design. The framework is based on

(1) Matching learning objectives of any two learning activities;

(2) Using both behaviour and outcomes as methods of assessment; and,

(3) Developing knowledge and skills in learning contexts that are consistent with the context of their use, or find ways of merging contexts.

Summary

In general, the structural frameworks reviewed address both the 'how' and 'what' of engineering design education and offer value and insight. Their primary drawback is the variance in approach, from the perspective of what aspect of design education the framework seeks to address and how comprehensive it intends to be. However, from the various frameworks (or partial frameworks) proposed in the literature, it is evident that deliberate design education must be aligned around a structural framework. Furthermore, the literature makes it possible to begin to synthesize an overall structural framework for engineering design education that borrows from the previously-cited work, but takes liberties to modify and enhance the frameworks to form a comprehensive and congruent whole.

A proposal for a comprehensive framework seeks to credibly and congruently incorporate the previously proposed syntheses of a holistic definition of engineering design (figure 2.1), desired outcomes of engineering design education (figure 2.2), and learning theory for engineering design education (figure 2.3). Furthermore, such a framework seeks to credibly and congruently incorporate syntheses of engineering design pedagogy and assessment and evaluation considerations for engineering design education, as these syntheses are developed in the following sections of the literature review.

Frameworks of Design

Apart from a structural framework for teaching and learning engineering design, a literature review on engineering design education would be incomplete without some mention of the available frameworks from which to view design itself. An extensive separate body of theory and research exists, with whole journals devoted to theories of design, representations and languages of design, and models of the design process (e.g. *Research in Engineering Design; Journal of Engineering Design*).

Many frameworks of design are normative methodologies of the design process. A frequently referenced foundational framework of process is that of Pahl & Beitz (1984). Based on work originating in the late 1970s, Pahl & Beitz are credited with bringing together an extensive body of knowledge about systematic design, as developed in Germany, to present a comprehensive theory of general engineering design. This theory takes the form of a normative methodology of the design process, which is broken out into four main phases, translated from German as clarification of the task (information collection with respect to requirements and constraints); conceptual design (establishment of function structures, the search for suitable solution principles, and their combination in concept variants); embodiment design (determination and development of the definitive layout in accordance with specifications); and detail design (determination of final arrangement, form, dimension, and properties). The substantial detail and development given to each phase positions Pahl & Beitz' model as arguably the most highly developed and established model of the engineering design process (Court, 1998).

Others have come after Pahl & Beitz and proposed variations on the theme. Reich (1995) notes that design frameworks have been classified into various conceptual categories, such as empirical/descriptive frameworks, prescriptive frameworks, classification by geographic origin, and mathematical frameworks. Cross (1994) characterizes descriptive models as describing the sequence of activities that typically occur in designing. Descriptive models usually emphasize the importance of generating a solution or conceptual design early in the process, and reflect a solution focus in design thinking. The initial solution is then subjected to analysis, evaluation, refinement, and development with some extent of iteration between these stages. The design process in a descriptive model is heuristic – that is, based on general guidelines and rules of thumb that lead the designer in a direction, with no guarantee of outcome. Cross' (1994) own descriptive framework of design includes the stages of exploration, iterative generation and evaluation, and communication.

Cross (1994) contrasts descriptive frameworks with prescriptive frameworks that seek to encourage or persuade designers to adopt improved ways of working. Prescriptive models are generally algorithmic or systematic procedures to follow, and are often regarded as advocating a particular design methodology. Another characteristic of prescriptive models is their emphasis on the need for substantial analytical work to precede the generation of conceptual solutions, in the effort to fully understand the problem and its important elements. The basic structure to prescriptive frameworks is that of analysis–synthesis–evaluation, and the framework of Pahl & Beitz (1984) is considered a foundational, comprehensive prescriptive model.

In other examples of design frameworks, Dym & Little (2000) propose a five-stage methodology of design, comprised of problem definition; conceptual design; preliminary design; detailed design; and design communication. Eide, Jenison, Mashaw, & Northup (1998) propose a ten-stage methodology of design, including identification of a need; problem identification; search; constraints; criteria; alternative solutions; analysis; decision; specification; and communication. In a final example, Pugh (1991) proposes a systematic design core for product development, consisting of market, specification, concept design, detail design, manufacture, and marketing. Regardless of whether a framework is characterized as descriptive or prescriptive, Fronczak (2001) aptly summarizes,

> Design methodology has been the subject of much intense scrutiny over the past couple of decades and a fairly well-accepted structure of the design process has been identified and promulgated throughout the engineering design community. While the details of the approaches of various authors on the subject may differ, the design methodologies presented by Cross, […] Pugh, […] Dym, and even Beitz, to name just a few, share a common fundamental approach (p. 333).

Departing from a methodological framework of design, Court (1998) proposes a broader framework of design, claiming that studies of engineering design in practice have demonstrated that several different types of design activity exist across all disciplines of engineering: (1) original design; (2) adaptive design; and, (3) variant design. In another attempt at a broader conceptualization at a design framework that is not linked to process or methodology, Schön (1983) describes "reflection-in-action" (p. 49), or design as a reflective conversation with the materials of a situation. This approach has been briefly summarized in a previous section of this literature review. Schön (1983) articulates three domains of reflection-in-action, which also form a design framework. The first domain is language (e.g. drawing, speaking). The second domain is implication – that is, noting the implication of earlier moves for later ones, on the basis of a system of norms. The third design domain involves shifts in stance, for example, from 'can' or 'might' to 'should' or 'must'. This last domain includes a balance between freedom, choice, and imperatives, a growing tendency toward commitment, and a view that shifts from the unit or the local environment to the global or total environment. In addition, Schön (1983) describes three components of the structure of design as reflection-in-action. First, the practitioner approaches the practice problem as a unique case, though with relevant prior experiences but with attention to the peculiarities of the situation at hand. Second, the problem is not given, but the practitioner must frame the problem. Third, the practitioner gives a performance with artistic quality.

Early exposures to engineering design in the freshman and sophomore years often focus on a methodology of engineering design, whether descriptive or prescriptive. This gives the learner multiple opportunities to understand a process of design by implementing a defined methodology. It also develops for the student the 'content' sphere of the holistic definition of engineering design (figure 2.1). The relatively bounded nature of a design methodology, often articulated in linear representations, provides a conceptual basis for the student as their understandings and experiences of engineering design grow more complex in later years of the curriculum. In the later years, the design methodology should be accompanied by the broader conceptualizations of engineering design, such as proposed by Schön (1983), which in turn develop an appreciation of and practice with the 'context' sphere of the holistic definition of engineering design.

Beyond frameworks of the overall design process, the literature also provides frameworks of portions of the design process or individual components of overall design. For example, Welch & Dixon (1994) and Madanshetty (1995) both provide frameworks of conceptual design as one component of design methodology. Welch & Dixon (1994) put forth a simple two-step framework of conceptual design, comprised of phenomenological design (transforming a functional requirement to a behavioural description) and embodiment design (matching the behavioural description to initial physical systems).

Madanshetty (1995) presents a more complex operational model of the cognitive processes at the breakthrough stage of conceptual design – "a glimpse into how ideas happen" (p. 232) – given that the conceptual phase of a design process relies on a series of breakthroughs to the general solution principles. The framework is characterized by the sensory perception P of a real world object, reality R. The sensory perception, P, is received and processed into two parts: its conceptual content C which moves skyward, and the form details of the specific context, D, which are relegated to the sea (figure 2.4).

In creative problem solving, the problem context is intensely worked upon during the preparation phase and digested into its abstract conceptual substance C1 and the form details D1. Should one, during the incubation aftermath following the preparation phase, find a suitable D2 that matches D1 on relevant but not identical features or dimensions, then C1 and C2 may also flash into fusion. This combination of concepts creates a C* which hitherto has not yet been seen or felt (figure 2.5). Problem solving is not complete until C* has been verified and embodied into a solution principle. The breakthrough (D1-D2 matching) occurs when the mind sees a context where the essential problem-solution is re-enacted on an unanticipated stage, or "a friendly platform. The events are characterized by an ease of metaphor-making; they re-enact the problem with strong, subjectively meaningful parallels" (p. 239).

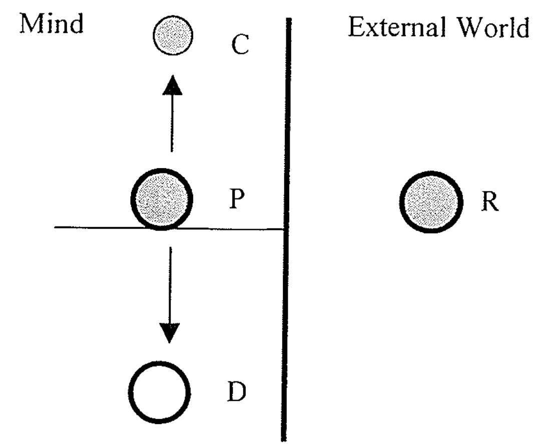


Figure 2.4: A Model of Perception Processing (Madanshetty, 1995, p. 234)

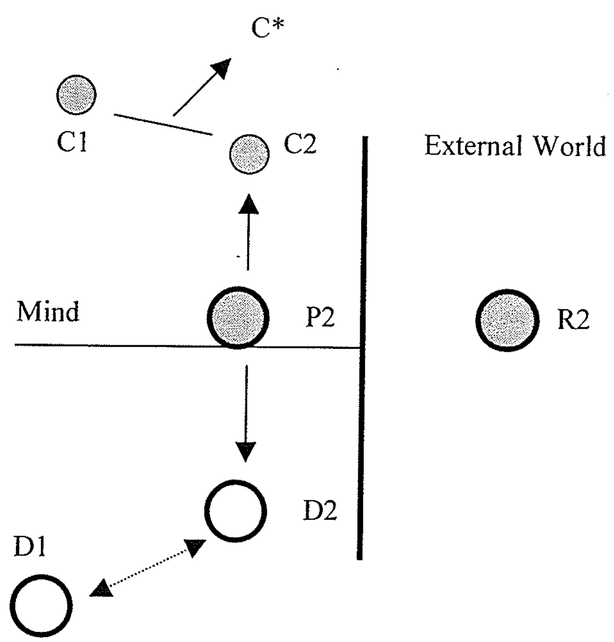


Figure 2.5: A Model of Design Breakthroughs (Madanshetty, 1995, p.236)

Schön (1983) echoes these latter thoughts of Madanshetty (1995) in his comments that in the process of design, there is a crucially important step often attributed to 'creativity' or 'intuition'. Schön (1983) argues that this experience is less random than it may seem, and calls it a "generative metaphor" (p.184), or outcomes of reflections on a perceived similarity.

Summary

To the untrained reader, prescriptive and descriptive frameworks of engineering design appear similar and appear to embody methodologies of the design process. The extent to which the methodology is delineated varies between authors, for example with Pahl & Beitz (1984) delineating four components (with extensive sub-components) and Eide et al. (1998) delineating a ten-step methodology. In practice, the factors that influence the design methodology to which the student is exposed relate to the experience and perspectives of the educator and the structural constraints of the course, such as course duration, textbook availability, etc. While the engineering student does not necessarily need lengthy exposure to the subtle nuances of each author's proposed methodology or design framework, engineering design education would be incomplete without some exposure to and practice with a basic design process of exploration/analysis, generation/synthesis, evaluation, and communication.

Pedagogy for Engineering Design Education

In addition to structural frameworks for design education (courses and curricula) and frameworks of design itself, the literature offers a host of advice and proposals on important dimensions of the teaching and learning process in engineering design. Two broad categories addressed in the literature are course- and delivery-related considerations and faculty roles in engineering design education.

Course-and Delivery-related Considerations

While most authors agree that creating good design education is a challenging task, the identified range of factors to consider in design pedagogy, as well as the importance assigned to various pedagogical considerations, varies between authors. Sheppard & Jenison (1997) draw a distinction between the nature and purpose of design – the production of an object or artifact – and the focus of design education – the students, and on helping them understand and experience the process and methods of realizing an artifact. They quote Larry Leifer's proposed three notions of design education: it is a social activity; learning to design requires being comfortable with ambiguity; and, that all education is re-education (1995, referenced in Sheppard & Jenison, 1997).

Gibson (1995) argues that the broad philosophy and methodology of design is best taught through active participation. Additionally, information, reference material, assistance, and feedback must be provided in a continuous manner and students must perceive new material as directly relevant to their own particular circumstances. Furthermore, design projects must be seen to be challenging, wide-ranging, and fun. Finally, new development in technology and computer software should be rapidly incorporated into the curriculum.

Harris (2001) echoes the view that engineering design is most effectively taught by integrating theory and hands-on projects in an active, experiential learning pedagogy. Flach (1999) likewise acknowledges the challenge of balance between the 'old' (i.e. the classical design experience, heavy on fundamentals, calculation-intensive, and rigorous in approach) with emerging active pedagogy for engineering design (i.e. team-oriented, computer-usage intensive, incorporating the development of oral and written communication skills).

Eder (1999) maintains that pedagogical and didactic procedures for engineering design must include:

(1) Explicitly presenting the theory in small but connected packages, via lectures and printed material;

(2) Explaining the appropriate methods related to the theory and presenting other available methods in this context; and,

(3) Providing practice by several progressively more challenging projects under tutorial supervision by experienced staff members, through all four years of study, ensuring continual back-reference and augmentation of previous work, ensuring that the normal steps of designing are followed, and providing gradual release from strict supervision (p. 38).

Finally, Wood (2001) presents decision-theory as a pedagogical approach for design education. This theory appears to be somewhat of an outlier with respect to the more standard recommendations for design pedagogy found in the literature. Decision theory as a pedagogical approach views design as a process of decision-making under uncertainty, and relates all student tasks to the process of resolving decisions and uncertainties relative to design process and design product. Pedagogy focuses on underlining the centrality of uncertainty in engineering design (how it affects both product and process) and providing students with formal means (tools) to manage and reduce uncertainty. By his own acknowledgement, this approach constitutes a product-oriented focus to the design process.

Faculty Roles

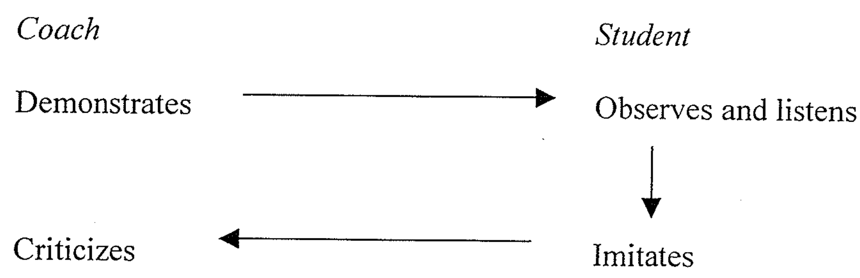
Congruent with principles outlined in the literature on design education, there is strong agreement in the literature on two aspects of faculty roles in engineering design education. First, traditional conceptualizations of the teaching role are not efficient, effective, nor adequate for design education. Second, design education requires newly-conceived roles, often articulated as the instructor as coach, the instructor as mentor, and less frequently, the instructor as moderator, mediator, and/or partner.

Bender (2001) proposes that the lack of congruence between traditional models of the faculty role and the requirements of faculty in design education exists because engineering design courses represent an exception within the strong deductive structure of engineering curricula. By contrast, the structure and tradition of engineering design is inductive. Thus, teachers likewise have to grow into a new role, being not so much the classical lecturer, but more of a trainer and partner of the students, by coaching their approach to teaching topics and moderating or modulating the process of learning. The new role becomes multiple roles and requires a balance of instruction, feedback, observation, and moderation.

Taylor, Magleby, Todd, & Parkinson (2001) consider effective coaching to encompass the three roles of mentor, mediator, and manager. The mentor role provides support by showing the way, being present, being aware, and being helpful. The mediator role provides a buffer between external reviewers and customers and the student. The manager or facilitator role guides the team in both team process and design process. All three roles exercised at appropriate stages are required for effective learning to take place.

Marin et al. (1999) further articulates instructor mentorship as teaching, coaching, counselling, and developing students to be competent and confident in applying their engineering skills to realistic problems. The goal of instructor mentorship is to design a learning experience whereby students can productively deal with the critical design issues they will face and develop a mastery of these issues. Creative tension is fostered in the presence of clear goals and feedback regarding attainment of the goals. The instructor as mentor allows opportunities for failure as well as success, providing tools to succeed and opportunities to fail. The mentor acts as a safety net, allowing the group to be innovative and creative, while ensuring the project stays on track. Instructor mentorship requires a balance between intervention and distance, and when failure occurs, the mentor assists the team in ascertaining why.

To assist in understanding, Schön (1987) provides a straightforward map of interventions and responses between the design student and the instructor as coach (p. 114):



The engineering-specific conceptualizations of faculty roles developed by Bender (2001), Taylor et al. (2001), and Marin et al. (1999) reflect many of the qualities of effective teaching that extend beyond design education and indeed beyond engineering education. Dressel & Marcus (1982) assert that the teacher is primarily a facilitator of learning. Thus, the obligations of the teacher include motivating individuals to learn by providing both intrinsic and extrinsic incentives; selecting and organizing learning experiences to encourage sequential, cumulative learning that promotes integration across disciplines and application to timely and timeless problems; adapting materials, experiences, and delivery system to the particular problems, context, and students; individualizing experiences by reference to student learning ability, maturity, past learning, aspirations, and learning styles; exemplifying or modeling thought processes for students; and, evaluating learning progress and developing learner independence in motivation, career and program planning, and evaluation of competence. The recommended teaching roles for engineering design faculty are supported by an extensive body of literature on effective teaching.

Other Considerations

Apart from the comments on appropriate pedagogy for engineering design and non-traditional instructor roles in engineering design, other authors offer comments on individual aspects of the overall structure and pedagogy of an engineering design course or curriculum. Sheppard (2001) and Linder & Flowers (2001) both highlight the importance of integration in the curriculum, creatively bridging the tension between educating students to be good analysts and good designers. Although the system is said to have many elements that support students in becoming competent in both design and analysis, Sheppard (2001) laments the absence of opportunities to use the elements in an integrated manner. Linder & Flowers (2001) likewise comment that students are not developing knowledge and skills that synthesize the subjects covered in the science and design curricula. They propose three reasons why core engineering science and engineering design activities may not be well integrated. First, any two learning activities are not integrated if one activity supports a different learning objective than is required by the other activity. Second, lack of integration is reinforced by an excessive focus on outcomes, rather than behaviours and outcomes, as the method of assessment, and third, by inconsistency between the contexts in which students learn knowledge and skills and contexts in which they apply them.

Court (1998) emphasizes the importance of well-defined educational objectives of any project work, as well as a solid understanding by the instructor of the difference between technical objectives and educational objectives in design education. Gorman et al. (1995) argue that a truly comprehensive approach to teaching design should cover invention as well, which in part may include allowing students to compare their problem-solving processes with those of actual inventors or designers. Holdsworth & Conway (1999) examined values teaching in design and technology courses at the secondary level in the United Kingdom, and determined that the most commonly taught values in relation to design were aesthetic, technical, economic, and environmental values. Finally, Delson (2001) addresses team motivation in design education, and argues that increased motivation can significantly affect the quality of outcomes.

Taken together, the preceding discussion on integration, objectives, invention, values, and motivation add to the rich tapestry of factors that both influence and constitute design pedagogy. All of these factors require serious consideration by the instructor in terms of achieving a congruent pedagogical model.

Summary

Pedagogical considerations related to the course and course delivery, faculty roles, and other pedagogical considerations offered in the literature add to a synthesis of a more comprehensive picture of pedagogical foci in engineering design education. The deliberate reorientation of faculty role in engineering design education is imperative. Schön's (1987) mapping of the coach-student interaction can be modified and augmented to present a more realistic picture of the complexity of student-faculty interaction in design courses. The mapping proposed in Figure 2.6 closes the loop of interaction, and allows for non-linear movement through the student-coach interaction cycle. In addition, the roles of both student and coach have been augmented to reflect the realities of a pedagogy that integrates engineering science or theory with engineering design.

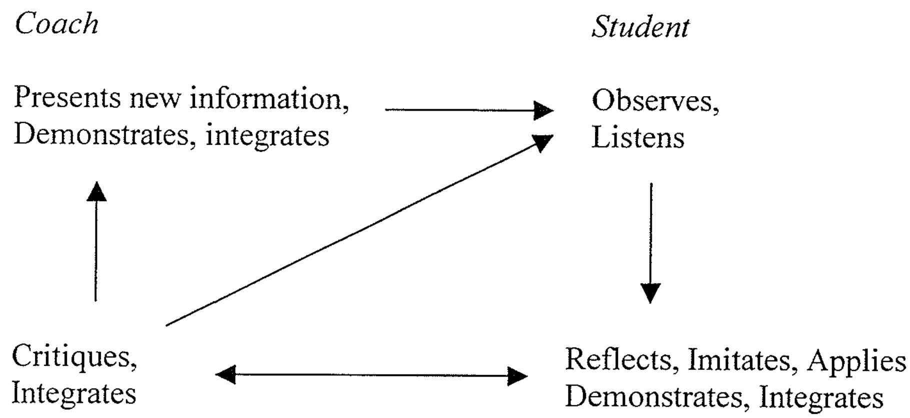


Figure 2.6: Proposed Model of Student-Faculty Interaction

The proposed model of interaction in Figure 2.6 is a detailed articulation of one of seven pedagogical foci proposed below (Figure 2.7). The pedagogical foci have been synthesized from the literature on salient pedagogical considerations for engineering design education. These areas of focus are deemed critical as areas of conscious deliberation and design in engineering design courses and curricula.

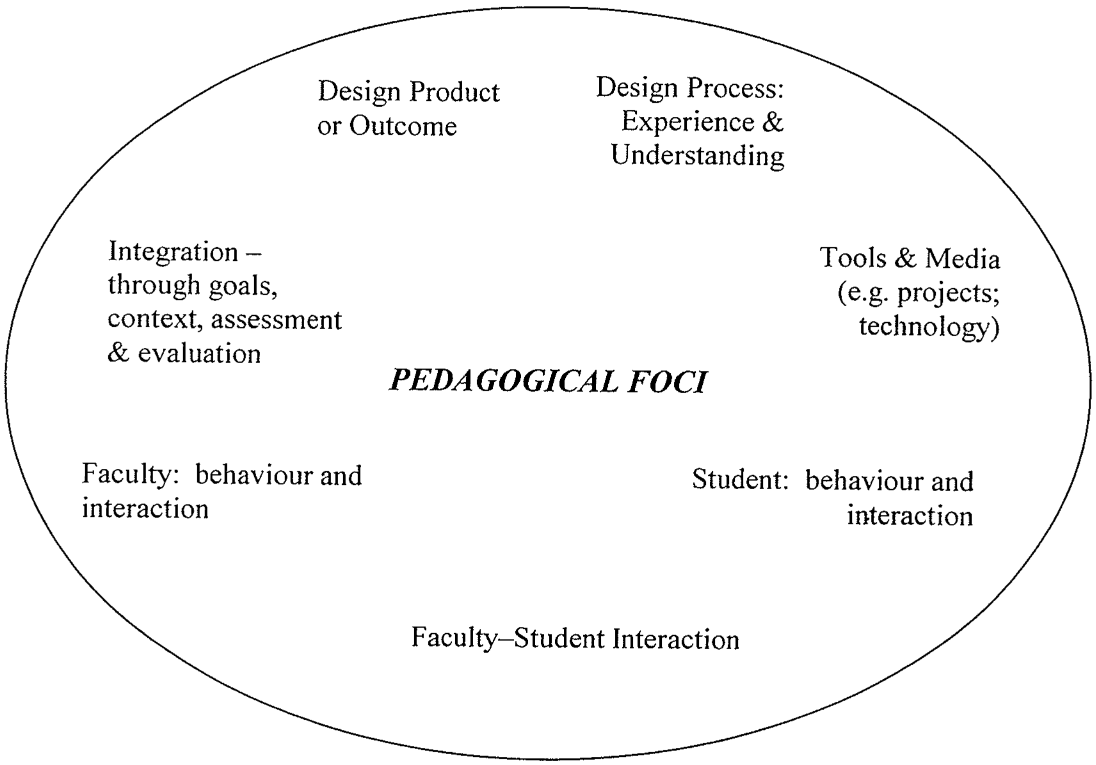


Figure 2.7: Proposed Pedagogical Foci for Engineering Design Education

Models of Engineering Design Education

Models for Engineering Design Education in Multi-course Formats

As this research focuses on a course series, or a trilogy of courses, a literature review of similar multi-course models for engineering design education is appropriate. Although the literature does not yield information on an exactly parallel format as the course trilogy under consideration in this research, a number of multi-course models for design education were identified and reviewed.

Kolar et al. (2000) describe a project identified as 'Sooner City', which threads one common four-year comprehensive design theme and design project throughout all courses of the civil engineering curriculum at the University of Oklahoma. Entering freshman students are assigned a theoretical plat of land that, by the time they graduate, will be turned into a partial design for a city. Design tasks encompass all sub-disciplines of civil engineering, including site planning and layout, sewer and water infrastructure, buildings, transportation systems, floodplain analysis, subsurface investigations, foundations, and earth-retaining structures. Implementation of the curriculum relies on a comprehensive database of raw data (e.g. hydrologic information, subsurface soil profiles, demographics, traffic flow, climate records, industrial users) and design criteria available to the students, a uniform 'look' to the information received through all courses, a digital photo gallery, a web page of overview and support to the project, and support structures. Cited advantages of the Sooner City approach are its ease of implementation and cost-effectiveness, its unifying function in the curriculum, students' exposure to real data, ability to integrate other departments, and its comprehensive nature, flexibility, and portability.

Wilczynski & Douglas (1995) describe the engineering design emphasis at the United States Coast Guard Academy. At this institution, design is treated in an incremental approach. Students are exposed to different tasks of increasing complexity in each year of the curriculum, with the view to treat design as a developmental process to be practiced incrementally during each year of the curriculum. The institution views design as an integral component of the students' education and claims to align each design exercise with the student's educational background and abilities. Freshman design introduces students to the design process by presenting several distinct design methodologies, coupled with a series of limited-duration hands-on group activities. Sophomore design shifts the emphasis to solving open-ended problems (primarily analysis-based) via the design process discussed in first year. In the junior year, some engineering fundamentals courses continue to rely on small scale design assignments with focus on a particular component, while others begin to expose students to the more comprehensive process of system design which spans an entire semester. Senior year design provides students with a unique design experience reflective of their chosen professions in a capstone project that encompasses all aspects of design. The capstone project is centered on solving an actual design problem from the US Coast Guard's civil engineering office backlog. Students work in teams and projects span an entire semester, with the target to reach 50% design stage (drawings and specifications).

Hyman (2001) presents a unique concept of design as the 'cornerstone' of the curriculum (vs. 'capstone design') that nonetheless maintains the position of the capstone projects as the unifying thread of the student's design experience at the University of Washington. He proposes a new role for the traditional capstone design course in that the outcome of the capstone experience serves as the cornerstone for an integrated sequence of design projects throughout the curriculum. The results of the traditional capstone design project course serve as the foundation for project activities in seven other courses. Each of the post-capstone stages would be undertaken as a student project activity in a non-capstone design-related course. The outcome of the fourth-year capstone design course would flow directly into first year Engineering Graphics (design documentation of the capstone project product), fourth year Engineering Entrepreneurship (business plans for the capstone project product), and third year Manufacturing Processes (prototypes of the capstone project product). These courses, in turn, flow into second year Product Dissection (redesign ideas of the capstone project product), fourth year Product Testing (performance data for the capstone project product), and third year Machine Design (revised designs). A graduate-level course in Design Management provides project coordination of the entire eight-course group. In this model, the capstone project is developed beyond the partial design stage, which typically occurs over the single fourth-year semester, albeit by student cohorts other than the capstone design students. The institution hopes to accomplish an integrated sequence of design experiences for students, with the exposure to realistic design activity such as follow-up refinements, implementation efforts, and commercialization.

Shaeiwitz (2001) asserts the superiority of integration of design throughout the curriculum ("holistic curriculum" (p. 479)) over a single capstone experience. He describes the design component of a chemical engineering curriculum at West Virginia University as having three parts. First, there is the use of a single design project for the second and third years. Second, there is a year-long group project led by a student chief engineer in the fourth year. Finally, there are individual design projects required in the fourth year.

Giralt, Herrero, Grau, Alabart, & Medir (2000) also describe an initiative at Universitat Rovira i Virgili, Spain, that places students in supervisory positions, although in a more complex structure than that described by Shaeiwitz (2001). The authors focus on horizontal and vertical integration of engineering design education, achieved through an early-design project. The project horizontally spans several first-year courses and vertically links those first-year courses with fourth-year courses in Project Management and Project Management Practice. The participation structure consists of a project board and sponsors (faculty of fourth-year project management courses), project teams composed of one project manager (a fourth-year student) and four team members (first-year students), internal clients (professors of the first year subjects), and external consultants (other faculty and staff from industry). The academic organization includes two fourth-year and four first-year courses.

Knox et al. (1995) describe the University of Oklahoma's attempt to respond to criticism of weak graduate competencies in non-technical engineering areas by re-vamping the senior capstone design course into a team-based design experience with strong industry collaboration. The industrial partner presented the project as a 60-acre parcel of land near their current offices, which they were interested in developing for office space and future corporate headquarters. The fourth year capstone class was then charged with a specific element of the design, and the continuity in the program came from the subsequent years' classes further development of the same design, taking the previous years' work and outcomes into account. In this way, the design tasks from 1992 to 1994 included (1) development of a master plan; (2) design analysis and environmental assessment; (3) site analysis and cost evaluation; and, (4) and retention pond, pedestrian bridge, and jogging path design. In this multi-course model, though, no single cohort of students was exposed to the project for more than one semester.

Finally, Hirsch et al. (2001) describe an initiative in which the engineering faculty at Northwestern University recently joined forces with the University Writing Program to develop a first year core course entitled Engineering Design & Communication. Over two quarters, students study the design process along with the communication process while working on conceptual designs for real clients. The stated goals are to develop students' skills in design, communication, and teamwork, and to allow students to view design and communication as complementary parts of an iterative and creative problem-solving orientation.

All of these examples address, to a greater or lesser extent and in various permutations, the assertion of ASME:

> An engineering design curriculum is more than a collection of separate and independent courses. It is a combination of interrelated courses that are carefully integrated to develop student abilities and knowledge throughout the program. This means that faculty collectively need to design and implement – and redesign as necessary – a curriculum that has multiple experiences and approaches to teaching design (Sheppard & Jenison, 1997b, pp. 258-259).

Other Models

In addition to multi-course formats for engineering design, two literature reviews illuminate other models for engineering design courses that are not necessary multi-course formats. Burton & White (1999) review methodologies for teaching design to freshmen, beginning with 320 ABET accredited schools in the US and narrowing the focus to 43 schools that met the study's criteria. In general, they found that the types of design courses offered at the 43 colleges and universities could be classified according to one of eight methods of teaching design (none of which are mutually exclusive). These methods included

(1) Reverse engineering (dissecting or deconstructing a common item to analyze, sketch, and discuss the components);

(2) Creating something useful (designing and testing an item that will successfully complete a task);

(3) Full scale project, often semester-long and resulting in a prototype or model;

(4) Small scale project, often based on team assembly and testing of an object that meets certain specifications (e.g. components of full scale projects);

(5) Case studies (discussing and analyzing design techniques and design concepts based on actual projects and/or failures);

(6) Competitions, ranging from peer-reviewed to industry-evaluated;

(7) Non-profit project, usually a real-world problem done for a local agency, community association, or group; and,

(8) Redesign of a local project, frequently a civil works project.

Burton & White (1999) additionally determined that Reverse Engineering appeared to be the preferred method to teach freshman design.

At the other end of the curriculum, Dutson et al. (1997) reviewed capstone courses in an effort to describe standard practice and the current state of capstone design education in the US. They classified capstone design courses according to those that have simulation versus authentic involvement, and designs for economic evaluation versus designs for construction. Capstone courses were found to vary from one semester to two years in length, and the course format trend was toward a structured class format with emphasis on teamwork and a particular design methodology. Many courses were found to utilize the format of the students comprising an imaginary engineering company contracting their services. Course content was generally found to be the design of a product or process, done in teams and/or individually, with accompanying lectures. Student performance was evaluated in subjective evaluations, reports, completed design work, and peer reviews. Faculty involvement in capstone courses varied from roles of supervisor, technical consultant, and/or client. Interestingly, Dutson et al. (1997) also determined that faculty interest in capstone design courses and faculty experience with design varies dramatically.

The examples of multi-course formats of design education take seriously the ASME challenge to integrate and develop student abilities and knowledge throughout the program. The cited examples of multi-course design education models, together with other examples of design education models found in the literature, also highlight the attempt to expose students to multiple experiences and approaches via design education, again as per ASME. Some of the characteristics and experiences commonly included in design education are articulated below.

Dym (1999) reviews several concerns related to engineering education, and strongly advocates for movement from the 'capstone' metaphor for design education toward a 'cornerstone' or 'backbone' metaphor. In a cornerstone or backbone approach, design is integrated with courses that have been primarily analysis-based, and as well, design is introduced from the freshman year and developed throughout the curriculum. Shaeiwitz (2001) calls this the "holistic curriculum" (p. 479) and values it as a superior paradigm to a traditional curriculum, which he sees as teaching courses as though they were unrelated. Gibson (1995) likewise advocates for engineering design as a "synthesizing activity" rather than "just another routine subject heading" (p. 93). The examples of multi-course models of design education cited previously take this challenge seriously by proposing a range of prototypes for cornerstone or backbone design.

Second, collaborative teamwork is a common feature of design education as described in the literature, focused on working at design in a multi-faceted way that mirrors the multi-faceted and eclectic nature of design, as well as focused on developing skills for professional practice (Jarvis & Quick, 1995; Tsang, 2000; Knox et al., 1995; Wilczynski & Douglas, 1995). In a literature review of over 100 papers related to engineering design courses, Dutson et al. (1997) found that 80% of capstone courses include team projects. The motivators to use teams include a need to develop what is considered an essential skill for today's engineers and to simulate industrial conditions. Additional motivators include a desire to develop and improve interpersonal and leadership skills, and to facilitate the use of larger projects in the course. The most commonly reported team size ranged from four to six members.

The formation of teams can be achieved in a number of different ways, including instructor-assigned or self-selected teams, teams based on homogenous or heterogeneous interest and academic achievement (Dutson et al., 1997), an interdisciplinary focus (within and beyond engineering disciplines) (Gorman et al., 1995), and teams with members from different years in the curriculum (Giralt et al., 2000). A number of authors highlight some of the most common difficulties encountered in the working of student teams, and propose factors that contribute to the differences between a group of people put to work together and a team of students learning cooperatively while working towards a common goal (Dutson et al., 1997; Gorman et al., 1995; Giralt et al., 2000). Faculty planning design courses should be aware that, in contrast to task-oriented work teams, learning teams must find ways to resolve queries among themselves rather than relying on the professor, find ways to check results within the team, and find ways within the team to resolve performance and learning difficulties related to poor attendance, inequitable work distribution, poor planning, and interpersonal conflict.

Industry collaboration and/or interaction and consultation with domain experts (both within and external to the university) arises as a third common feature of design education. In many instances, the industrial collaborator acts as the project client (Knox et al., 1995; Wilczynski & Douglas, 1995), but the role of the industrial partner or collaborator can include provision of financial support, equipment and materials support, technical consulting, liaison engineering, awards, evaluation of final designs, classroom or laboratory presence and/or instruction, and feedback on course design (Gorman et al., 1995; Dutson et al., 1997; Doepker, 2001b). Industrial collaboration can encompass collaboration from a wide variety of groups, including engineering discipline-specific industries, the public service and not-for-profit sector (Dym, 1994b), faculty from other courses (Shaeiwitz, 2001; Giralt et al., 2000), and groups in a sponsoring position to the overall institution (e.g. the United States Coast Guard Academy) (Wilczynski & Douglas, 1995).

Magleby, Todd, Pugh, & Sorensen (2001) and Little & King (2001) articulate basic principles of recruitment, selection, and management of industry-sponsored design projects, with the view of fitting the design project into the epistemology of the curriculum, rather than vice versa. Common principles include the need to choose a very specific problem not on the critical path of the company, that requires design over data collection or new product development, that is achievable within the timeframe given, to which the industry can assign a liaison member, the scope of which is manageable to the student team, and to which the industry is prepared to afford flexibility in outcomes and permission to fail.

Closely related to the issue of industry collaboration is the common feature of choosing design projects with a local tie-in or buy-in for the project team and/or the class. Marin et al. (1999) and Sheppard & Jenison (1997b) develop the sentiment that an optimal and meaningful design experience depends on a worthwhile project or careful project selection. This may include projects in collaboration with industrial clients in close proximity, with close ties to the local economy or the engineering discipline, projects related to an event of local importance or significance, and projects centered on the local landscape (Tsang, 2000; Dutson et al., 1997; Kolar et al., 2000; Knox et al., 1995; Wilczynski & Douglas, 1995).

An explicitly planned inter-disciplinary or multi-disciplinary feature to design education is a fourth common element found in literature. This inter-disciplinary feature may extend between engineering disciplines or between engineering and non-engineering disciplines (Dutson et al., 1997). Gorman et al. (1995) describe a course teaching invention and design by combining engineering, social sciences, and humanities. The course is listed as a fourth year engineering and a third year psychology course in the University of Virginia catalogue. Noble (1998) describes a capstone design experience at the University of Missouri – Columbia with the objective to integrate general education courses within engineering, social sciences, and humanities with courses specific to the engineering discipline. Kolar et al. (2000) similarly describe a potential integration between engineering departments and non-engineering departments for design education at the University of Oklahoma. Apfel & Jeremijenko (2001) describe a new curricular offering at Yale University that brings together engineering, computer science, and management students to create new projects and business plans at the graduate level.

A fifth theme is that written and oral communication requirements are built into the vast majority of design courses, again in an attempt to develop non-technical professional competencies (Gorman et al., 1995; Dutson et al., 1997; Tsang, 2000; Dym, 1994b; Knox et al., 1995; Wilczynski & Douglas, 1995; Hirsch et al., 2001; Shaeiwitz, 2001). These requirements may take the form of proposals, progress reports, interim and final oral and/or written presentations and reports, and oral examinations.

Related to the inclusion of oral and written communication requirements into design education is a common requirement for documentation of (the design) process, in the form of a portfolio, report, paper, or reflective work. Dutson et al. (1997) refer to a literature search, project or process synthesis and weekly status reports as common requirements in design courses. Other authors refer to requirements for individual and team notebooks, essays on non-technical factors related to the design, and student portfolios that act as an interview tool when seeking employment, a technical reference tool, and an assessment tool (Gorman et al., 1995; Tsang, 2000; Kolar et al., 2000).

A sixth trend is that while the design project as the focal point of design education is so common as not to have been explicitly mentioned, most design courses nonetheless give attention to lecture content and readings designed to complement the technical aspects of design and reflect on the non-technical contexts of engineering. Commonly cited topics for lectures in design courses include a discussion of the engineering profession and professionalism; ethical considerations; definitions of design; design theory and process or methodology; design tools; system development; project management operations; team dynamics; documentation, communication, and presentations; leadership; safety; cost estimations and economic analyses; technical background on the project area; legal considerations, contract law, and patent law; and, product marketing (Gorman et al., 1995; Dym, 1994b; Dutson et al., 1997; Knox et al., 1995; Flach, 1999).

Finally, many design courses are structured to provide and develop leadership experiences for the students. These experiences may place the student as project manager (Giralt et al., 2000; Hyman, 2001), as lead engineer (Marin et al., 1999), or as student chief engineer (Shaeiwitz, 2001).

Taken together, the models of multi-course design education and the themes or trends in design education as reviewed in the literature provide a template to which design faculty can turn as a starting point in creating design courses and curricula. The models and trends simultaneously reflect the complexity of the design process in engineering. In turn, this complexity presents challenges for how the learning that takes place in these courses can be assessed and evaluated.

Assessment and Evaluation in Engineering Design Education

The previous sections of this literature review have yielded numerous components of a comprehensive framework for design education. These components have included a holistic definition of design, desired learning outcomes of design education, a learning theory for engineering design, and pedagogical considerations in engineering design. A final piece of a comprehensive framework for design education is to address assessment and evaluation components. The issue of assessing and evaluating engineering design education can be seen from a number of perspectives. These perspectives include, but are not limited to, student behaviour in design courses, student design competence, student design outcome (product), and the effectiveness of the design course in meeting its goals and in teaching design effectively.

Challenges

Several authors highlight some of the inherent difficulties of assessment and evaluation in engineering design education, due to common characteristics of design courses and the nature of design itself. Sheppard & Jenison (1997b) indicate that it is much more difficult to grade student work when there are multiple right answers (as in design), when students may be working on different design problems, and when the process or path to the solution is as important as the solution itself. These problems are generally compounded when the work is team-based, given that individual effort is difficult to identify and reward (Dutson et al., 1997). Feland & Leifer (2001) concur that with the diversity of projects that may be underway in a single class, it is difficult to predict team success. It is also challenging to assess team performance relative to one another (as opposed to a criterion-based approach), since each project has its own innate issues and unique circumstances. Atman & Bursic (1996) echo that while design experiences undoubtedly provide some positive experiences for participating students, it is extremely difficult to assess the effectiveness of the courses because their goal is to teach an engineering skill that is, in large part, a process skill. Processes such as design and problem-solving are difficult to measure, and course instructors are often unsure of how to weight evaluation in a combination of assessing student competency in the design process, quality of the design process, and quality of the product.

Part of the challenge that educators face in assessing and evaluating engineering design education is a lack of guidance or credible precedent in the literature. Dutson et al. (1997) indicate that although the literature is filled with positive comments from students, instructors, and industrial sponsors who have participated in capstone design courses, the nature of the courses and lack of a well-planned assessment and evaluation strategy often leads to a purely subjective evaluation with little or no rigorous evidence of actual benefits. Educators often claim to be convinced of the value of the experiences, and only on more limited occasions has a more objective approach been used to weigh the benefits of course or curriculum innovations against costs. Campbell & Colbeck (1998) also lament that if the issue of assessing student design competence is discussed at all, it is embedded in articles whose purpose is often to provide descriptions of so-called innovations in design education.

Current Practices

While challenges persist, the literature does provide a picture of how assessment and evaluation are currently being conducted, at several levels, within engineering design courses. Student performance is often assessed by some combination of the following: design process or design history documents such as portfolios or journals; completed reports; completed design work (product); and, formal examinations on specific material covered in the course or standardized tests of domain knowledge. Assessment and evaluation of student performance is generally carried out by some combination of faculty, industry representatives (juries or design reviews), peer evaluation (juries or design reviews), and self-evaluation, and the correspondence between evaluation by others and self-evaluation (Dutson et al., 1997; Campbell & Colbeck, 1998; Sheppard & Jenison, 1997b; Shaeiwitz, 2001; Tsang, 2000; Marin et al., 1999). Team performance is often assessed by some combination of peer reviews and self-evaluations (Dutson et al., 1997).

The structure of the course itself is often assessed by some combination of project sponsors (continued support, interest in course graduates); students and alumni (via questionnaires, surveys, or 'one-minute quizzes'); educators; job/graduate school placement; employer surveys, and student retention statistics (Dutson et al., 1997; Campbell & Colbeck, 1998; Burton & White, 1999). Another source of feedback on structural components of the course is the accrediting body for the curriculum.

There are also ample examples in the literature of faculty that describe a 'new' or 'innovative' approach to teaching design with a focus on the goals, objectives, logistics, and implementation mechanics of the course. These descriptions pay varying degrees of attention to discussing a credible assessment and evaluation strategy, data, or findings. Often, discussions related to assessment and evaluation are based on non-rigorous, subjective measures. Several examples of descriptions found in the literature are highlighted below.

Kolar et al. (2000) in their description of the 'Sooner City' model for integrated design across the curriculum do not comprehensively address the issue of assessing student learning. Disconnected references are made to on-line quizzes, one-minute quizzes, portfolios, and practicing engineers evaluating students in the capstone course. In terms of assessing the curriculum structure in its ability to teach design, the authors state that the evaluation plan for the project includes well-established techniques, such as formative and summative evaluations and project-specific diagnostic exams developed by the project team. With a control group going through a 'regular' civil engineering program, formative information is gathered through student interviews and questionnaires, faculty interviews, and observations from the Oversight Committee. Summative information is gathered through retention statistics, standardized exams, performance in capstone courses, scores on the national licensing exam, and surveys of employers and graduates.

Wilczynski & Douglas (1995) likewise do not address the assessment of student learning in their description of design integration across the United States Coast Guard Academy curriculum. Evaluation of the particular curriculum structure to teach design effectively is noted to be through "predominantly positive feedback,...students seemed to enjoy the exercise and at times worked on them with vigor not usually applied to typical homework,...faculty echoed this enthusiasm for design exercises in the engineering...course" (p. 239).

In another example, Knox et al. (1995) determined the effectiveness and success of the design curriculum through quantitative and qualitative student evaluations (standard course evaluation questionnaires and program exit interviews, respectively) and practitioner evaluations. They conclude that "as expected, the new format has been praised by the industrial participant and...has generated enough interest to...recruit a second industrial sponsor. In fact, the new course format has been discussed at the local technical society meeting" (p. 6).

Gorman et al. (1995) describe a way of teaching invention and design through multi-disciplinary learning modules, but fail to provide a structured and coherent reference to assessment and evaluation of the initiative. Disjointed comments across the four modules refer at times to how students' work was evaluated, what the results of the evaluation of students' work were, and how the experience was evaluated. The final section attempts to review how the four design modules achieved the goals of the course, and definitive statements are offered without evidence nor indication of methodology to arrive at the conclusion. In terms of overall course evaluation, general success is claimed exclusively from students' comments of enjoying aspects of the course. Course evaluations were compared to previous years' cohorts, although uncontrolled for pre-existing conditions such as differences in mean GPA.

Hirsch et al. (2001), in their discussion of a freshman course integrating engineering design and writing/communication, acknowledge the lack of long-term assessment and evaluation data for the course. Nonetheless, the authors posit that a growing body of information exists to support a positive assessment of the interdisciplinary course. This statement is supported by indicating that engineering faculty at the institution perceive that the participating students produce higher quality reports and presentations than other students at higher levels, that senior design professors claim to see the seniors who have participated in the course as freshman approach senior design and teamwork in a more methodical and positive way than in the past, and that positive feedback exists from engineering school advisors, faculty, administrators, engineering deans, alumni, and trustees.

Dym (1994b) describes a freshman design course that stresses the open-ended nature of design in a project-based context. Upon describing the structure of the course, the discussion of assessment and evaluation is missing, and is summarized in the comment that "all in all, the course has proved to be successful, based on evaluations by students and the faculty (and also according to the college grapevine!)" (p. 7). No other assessment and evaluation details are given.

The preceding examples have demonstrated a general lack of information in the literature related to – and the implied lack of planning for – assessment and evaluation in the described design education initiative. By contrast, Giralt et al. (2000) give more attention than most authors to describing a comprehensive assessment and evaluation strategy in their description of the integration of four first-year and two fourth-year design courses. Assessment of student performance for first-year students takes place according to criteria negotiated between team leaders (fourth-year students), sponsors, and internal clients. These criteria may include self-assessment and cross-assessment within teams, final product, final presentation, communication, and knowledge. Assessment of student performance for fourth-year students takes place according to criteria negotiated with sponsors. These criteria likewise include self-assessment, evaluation by first-year students ('subordinates'), quality of management provided, performance of the first-year students within one's team, ability to properly grade the first-year students within one's team, final presentation and report, and day-to-day management and coaching within first-year classes.

Giralt et al. (2000) further describe assessment of the curriculum as including objective indicators (academic achievement of students, retention and evolution of involvement of students, and trends in numbers of students wanting to participate in the project) and feedback from those involved (using surveys, interviews, group discussions, final reports, presentations, team close-out reports, and anonymous opinions and questionnaires). Interim conclusions were that satisfaction from all project participants is high and that effective teaching and learning is taking place.

The majority of examples found in the literature demonstrate that while faculty are eager to distribute information on new course and curriculum initiatives, assessment and evaluative information is often only available on a time lag of several years. The examples also demonstrate that attention to assessment and evaluation components varies widely between faculty, and that it is rarely reported well or comprehensively. This may stem from a lack of initial planning for assessment and evaluation when devising the course or curriculum change, which would generally be congruent with the way many courses are modified by faculty (i.e. in a trial-and-error fashion based on accumulated experiences, but less often in a systematic or methodical way, particularly when only one course is involved).

For example, Phillips & Duron (2001) describe the fall-out of an ABET visit to Harvey Mudd College, known for its high-level student-team project work performed for outside sponsors in the Engineering Clinic. The faculty were shocked to hear ABET feedback that although their program was rated as outstanding, they lacked formal, documented assessment practices directed toward systematic, continuous program improvement. Although much thought and planning had gone into the structure of the Engineering Clinic, the faculty later acknowledged that assessment and evaluation strategies had been both under-planned and planned without consideration for gathering solid baseline or comparison data. Subsequently, they redoubled their efforts to correct this shortcoming.

Also missing from the assessment and evaluation discussions that are found in the descriptions and discussions of design courses and curricula is explicit mention of a feedback loop for continuous improvement. While this may be assumed by some authors or may be taking place and not documented in the literature, the overwhelmingly positive characterizations given to the various course and curricular descriptions also seem to preclude the authors from believing that a feedback or continuous improvement loop may be necessary. Doepker (2001) affirms that although a number of successful assessment models have been developed, nearly all have the same major elements: outcomes, measures, and continuous improvement.

Assessment and Evaluation in a Broader Context

It is helpful to consider assessment and evaluation theory in a broader context than constrained within a specific example of a course or course series. In a wider discussion on assessment and evaluation in engineering education, Bucciarelli et al. (2000) assert that a major challenge to (engineering) tradition is the need for assessment of curriculum renovations, assessment of students, and assessment of faculty. The authors highlight the need to incorporate assessment planning at the outset of planning and far prior to committing to curricular changes. The authors further highlight the need to look at multiple ways of assessing, seen broadly as qualitative and quantitative measures, and looking at the student's total experience by using different modes and means of evaluating student efforts. The recommendations challenge traditional beliefs about who are valued students, where they are headed upon graduation, what counts as research, and what forms of knowledge and kinds of skills are truly needed.

Ewell (1998), writing from outside of the engineering community, discusses trends in assessing student learning and applies the discussion to the outcomes-based assessment criteria of ABET EC2000. Ewell acknowledges that for engineering faculty to embrace and understand the assessment framework required by EC2000 requires "a significant shift in operational mindset", best described as "done well, the assessment of learning is a form of scholarship" (p. 107). Underlying the shift is the conviction that assessment is less a 'mechanism' than a mindset, and that the familiar values of scholarship can be turned toward the core activities of teaching and learning. Assessment is broader than collecting information or demonstrating the attainment of learning objectives; rather, assessment is "embodied in the use of information as part of essential decision processes, where decisions may occur" (p. 107), and involves information on inputs, processes, and outcomes. Assessment further resembles scholarship in that it is never really completed.

Ewell (1998) further provides a context for the shift that EC2000 represents by drawing parallels to the environmental forces that are acting upon all disciplines, including growing demands for public accountability, growing internal pressures to become more productive, and changes in the way instruction is designed and delivered. These changes include movement toward performance-based demonstrations or competency-based approaches, and the increasing role of technology in teaching and learning. Some trends in assessment methods over the past two decades include a shift from standardized tests to performance-based assessments, from 'teaching-based' to 'learning-based' models of student development, and from assessment as an 'add-on' to more naturalistic assessment approaches embedded in the delivery of content. Ewell (1998) goes to some length to assure engineers that the move toward assessment that EC2000 represents is not limited to engineering nor disjointed from general trends in assessment theory and practice, and encourages engineers to understand assessment fully and adopt it readily. (Interestingly, the CEAB has stated that although they agree with the concept of using output measures as per EC2000, they believe that more time is needed for the full development of the EC2000 system and to assess its long-term effects (Canadian Council of Professional Engineers, 2000, p. 11). Although the CEAB claims to have adopted a number of output measures in its own accreditation process, such as the evaluation of capstone design projects, transcripts and examinations, and self-evaluations by institutions, the accreditation criteria in Canada remain largely tied to specific course and credit-hour requirements in the form of Accreditation Units).

Shaeiwitz (1996), McGourty, Sebastian & Swart (1998) and Christy & Lima (1998) also discuss the movement towards outcomes assessment in engineering generally and propose various vehicles by which to achieve the goals of outcomes assessment. In the literature on assessing the impacts of technology in teaching and learning, Ehrmann (1998) cautions that solely assessing outcomes neglects the experience or process or strategy-in-use to achieve the outcome (as highlighted by Ewell (1998)). He further states that a uniform impact assessment can be augmented by a 'unique uses perspective', that is, assessing the extent to which the learner has taken the information to achieve or move toward personal goals, which will differ between learners.

Finally, the American Association for Higher Education Assessment Forum has published and widely distributed nine principles of good practice for assessing student learning. These principles include beginning with educational values; reflecting an understanding of learning that is multidimensional, integrated, and revealed in performance over time; applying assessment to a program with clear, explicitly stated purposes; affording attention to experiences as well as to outcomes; making assessment ongoing rather than episodic; involving representatives from across the educational community; using assessment to illuminate questions and issues that people really care about; including assessment in a larger set of conditions that promote change; and viewing assessment as a way to meet responsibilities to student and to the public (Walvoord & Johnson Anderson, 1998).

As a final note on assessment and evaluation, Yoshino (2001) argues that parallels exist between the theories of engineering design and theories of assessment in higher education. Design and assessment keep their respective enterprises (engineering and higher education, respectively) connected to their social purposes, and the theories of design and assessment have at least four common elements. These are: identified goals, objectives, and criteria; systematic generation of information; systematic evaluation of information generated; and, systematic comparison of information generated against known goals, objectives, and criteria. Most importantly, the role of evaluation in both theories is to improve outputs or outcomes by means of a feedback loop. These commonalities may suggest faculty who teach engineering design are predisposed to the purposes and methods of assessment.

Summary

The paucity of credible and rigorous discussion in the literature regarding assessment and evaluation of the various components of engineering design education is not unique to engineering or to the discussion of design. In discussing the evaluation of the effectiveness or value of new technologies and new technology uses in teaching and learning, one can similarly cite a scarcity of credible, rigorous research and much lip service paid to the apparent benefits of new technologies. Gilbert (1996), president of the Teaching, Learning, and Technology Group (an affiliate of the American Association for Higher Education) proposes why, despite this reality, technology use in education continues to move ahead. As with other institutional changes, the seeds grow from the initiatives of individual faculty members working in relative isolation from one another. In a statement that could perhaps be applied with some credibility to engineering design education, Gilbert (1996) claims, "commitment to change based on accumulated experience is outpacing the availability of conclusive research results" (p. 10).

The cited literature again allows one to synthesize an assessment and evaluation framework for engineering design education, summarized below in Figure 2.8. This framework can be applied at various levels: the student, the faculty member, the course, and the curriculum. In the proposed assessment and evaluation framework, the starting conditions include values, goals, and purpose, as well as instruments and measures, and broad representation in the assessment and evaluation process. The values and the goals and purposes of engineering design education will vary from program to program and from institution to institution. Therefore, it is appropriate to spend a considerable amount of time discerning the unique values, goals, and purposes that apply to the particular element being assessed, as well as the goals and purposes of the assessment and evaluation exercise.

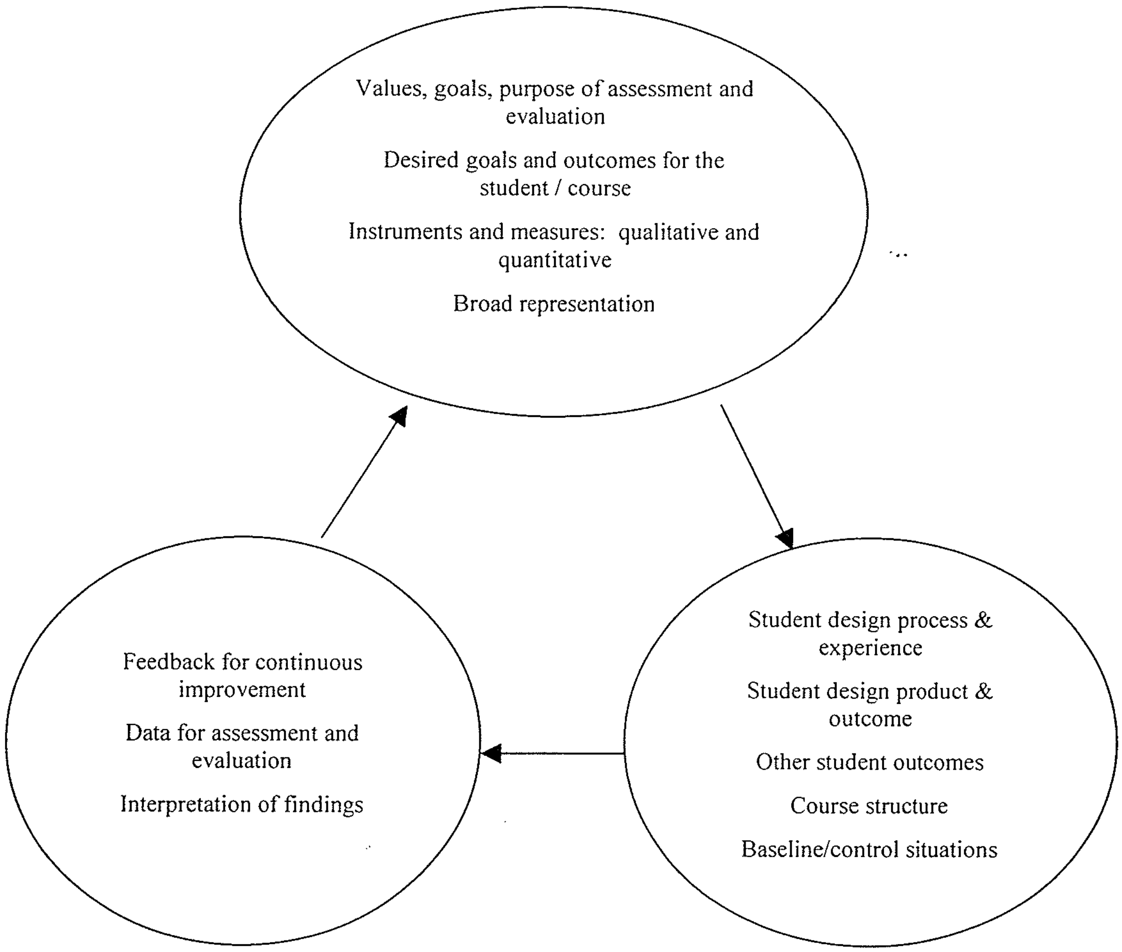


Figure 2.8: Proposed Assessment and Evaluation Framework for Engineering Design Education

A Comprehensive Framework for Engineering Design Education

The development of a framework for assessment and evaluation in engineering design education completes the final piece of a comprehensive framework for engineering design education. Such a comprehensive framework integrates the individual elements synthesized previously, including a holistic definition of design, desired outcomes of engineering design education, a learning theory for engineering design education, pedagogical considerations in engineering design education, and assessment and evaluation considerations in engineering design education. To be credible, these individual pieces must be developed to be congruent with one another, and then integrated into a final framework in a manner that engineering design faculty can relate to, understand, and find meaning in.

The sum of the themes and findings reviewed in this chapter, relative to the multiple curriculum considerations for engineering design education, and the individual frameworks for individual curriculum dimensions developed throughout this chapter have culminated in a final comprehensive framework for engineering design education, as proposed in Figure 2.9. The framework is comprised of four main elements of preparation, structure, administration, and assessment and evaluation. The double-headed arrows indicate that major components and the sub-components listed must be congruent with one another, contribute to the development of one another, and are dependent on one another to achieve an integrated whole.

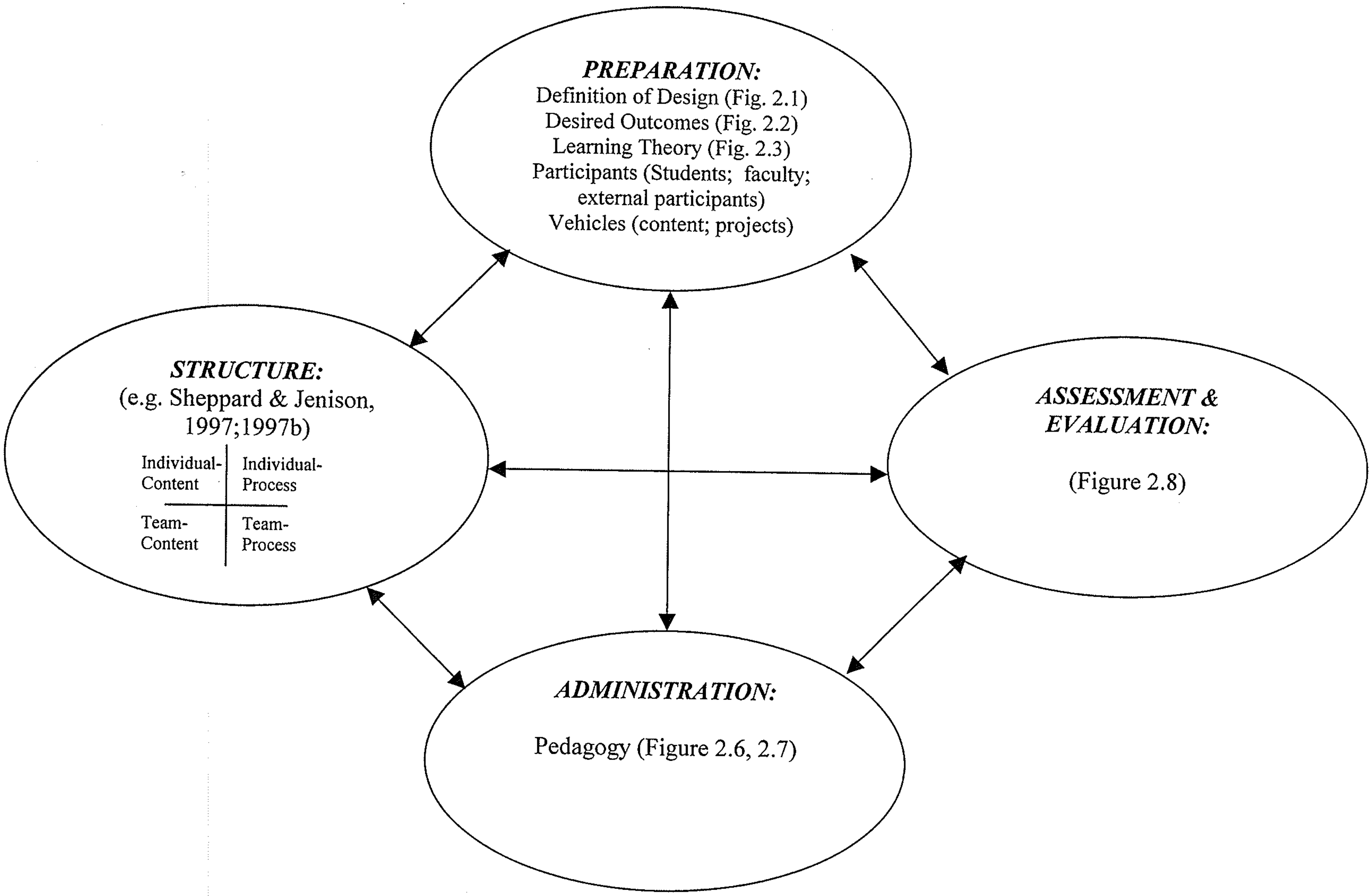


Figure 2.9: Proposed Synthesis of a Structural Framework for Engineering Design Education

Chapter 3:

Methodology

Introduction

The focus of this research as described in Chapter 1 (Introduction) was to explore, in depth, teaching and learning experiences in the Biosystems Engineering Design Trilogy courses (DT) in the Department of Biosystems Engineering at Western Canadian University, and to determine how these three design courses, individually and in synergy, contribute to learning engineering design. To respond to this broad query, the following research questions were posed:

- How do faculty, students, and industry cooperators of the DT conceptualize design?
- What are the critical goals of design education, as seen by faculty, students, and industry cooperators of the DT?
- What are effective teaching and learning strategies in design education, as seen by the faculty, students, and industry cooperators of the DT?
- To what extent do faculty, students, and industry cooperators of the DT think the current design education structure is successful?
- To what extent do the DT courses, individually and as a trilogy, reflect elements of a comprehensive literature-based conceptual framework for design education? How can a comprehensive literature-based conceptual framework for design education be applied to improve the courses?

The review of literature (Chapter 2) demonstrated that a growing body of literature is available to address strategies for teaching engineering design and planning engineering design education. However, the literature review also demonstrated that pedagogical analyses of design courses are criticized for under-reporting of the analysis or research methodology or lack of attention to reporting limitations of the study. A gap in the literature is a strong critical analysis of the teaching and learning processes associated with engineering design education. This research sought to address this gap.

The nature of the research questions lends itself to qualitative research methodology. In addition, the preponderance of quantitative inquiry in engineering research (as it relates to discipline research and research into teaching and learning processes in engineering) is balanced by qualitative inquiry into some of the same areas previously and currently explored in a quantitative manner. This chapter outlines the specific methodology used to respond to the research questions. The methodology was designed to

- apply qualitative inquiry to explore an area of curriculum that has traditionally been explored in a quantitative manner, to address gaps in knowledge about design education;
- be consistent with a qualitative inquiry paradigm by using in-depth one-on-one and focus group interviews to explore participants' attitudes and perceptions of engineering design education and how participants conceptualize goals, learning strategies, and the effectiveness of engineering design education;
- use existing research as a conceptual framework to guide the study;
- be workable within the research environment (site, settings & participants); and,
- yield meaningful results that are also conceptually accessible to the research environment (settings & participants).

The first part of this chapter describes the qualitative data collection methods and data analysis methods, and discusses the role of theory in the study, trustworthiness or evaluation criteria for the study, and the role of the researcher in the study. This is followed in the second half of the chapter by a detailed articulation of the research site, participant selection and recruitment procedures, protocols for data collection and data analysis, ethical considerations of the study, and limitations of the methodology.

Methodology may be described as the data collection tools or techniques of any given research design. However, methodology may also be more broadly defined as the process of research, the form of argument, or the overall strategy for resolving the choices available to the researcher (Schulman, 1997; Bogdan & Biklen, 1998). It is this broader definition that this chapter seeks to address. Because this research is being conducted and written for an audience accustomed to quantitative methodology and terminology, the chapter begins with a brief overview of qualitative models relative to quantitative models of research. In later sections, additional comparisons are at times made to quantitative research models, in order to describe and highlight salient features of qualitative inquiry that may be unfamiliar to some readers. The descriptions of qualitative methodology elements provided in the later sections also inform the reader of the specific methodological framework used in this study.

Qualitative Methodology: An Overview

This research exploring a course trilogy in engineering design utilized a qualitative research methodology. Due to the research setting being an engineering department with its associated quantitative inquiry norms, an overview of qualitative methods relative to the quantitative status quo in engineering is provided. The terms 'qualitative' and 'quantitative' are descriptors of distinctly different inquiry paradigms. A paradigm is defined as a worldview or a network of underlying principles and philosophical beliefs that advance assumptions about the social world, about how science is conducted, and what constitutes legitimate problems, solutions, and criteria of proof (Ely, Anzul, Garner, & McCormack Steinmetz, 1991; Creswell, 1994). It is on these features that the research differed from quantitative research on engineering design education reported in the literature.

A qualitative methodology is an inquiry of understanding a social or human condition, experience, or problem. It is based on building a complex, holistic picture, formed textually and analyzed inductively (Creswell, 1994). Qualitative research reports detailed views of small numbers of participants and is conducted in a natural setting. Outcomes of qualitative inquiry include description, interpretation, hypotheses, and grounded theory (Bogdan & Biklen, 1998; Hittleman & Simon, 1997; Glesne & Peshkin, 1992). By contrast, a quantitative methodology is – in very broad strokes - often an inquiry into a social or human problem, based on testing a theory composed of variables. Often (but not exclusively), actions or outcomes of relatively large numbers of randomly selected subjects are reduced to numerical values and analyzed with statistical procedures. Frequently, outcomes of quantitative inquiry are to establish fact, show statistical relationships, or determine whether predictive generalizations of a theory hold true (Creswell, 1994; Schulman, 1997; Bogdan & Biklen, 1998).

The purpose of a qualitative model of research is motivated by keywords 'interpretation' and 'meaning'. Qualitative research develops a holistic, complex, and rich description of a situation in order to provide interpretation and to develop meaning, to understand and relate actors' perspectives and experiences as they live and feel them, to develop concepts, to describe multiple realities, and/or to develop grounded theory (Glesne & Peshkin, 1992; Bogdan & Biklen, 1998). The purpose of a quantitative model of research is motivated by keywords 'verification' and 'generalization'. Quantitative research is carried out to provide statistical description, to establish fact, to test theory, to predict, to attribute causality, and to facilitate generalizability of findings to the larger population. In general, qualitative inquiry may be described as having an overarching concern with process, while quantitative inquiry has an overarching concern with outcome or product (Hittleman & Simon, 1997; Glesne & Peshkin, 1992; Ely et al., 1991).

Qualitative methodology is described as iterative, interactive, hermeneutic, intuitive, and open (Guba & Lincoln, 1989). The research design is flexible and continues to be developed as the research progresses. The design is continually influenced by the emerging understandings of the researcher, the data provided by the participants, and by the research context. By contrast, quantitative methodology is described as linear, closed, and deductive. Data collection and analysis techniques have been defined before any data collection occurs (Guba & Lincoln, 1989).

In engineering research, the quantitative inquiry paradigm is the status quo. Quantitative models have also been called traditional, positivist, experimental, and empiricist models and the paradigm has been frequently referred to as the scientific paradigm (Creswell, 1994; Lincoln & Guba, 1985; Guba & Lincoln, 1989). Quantitative models have a much longer history than qualitative models. They have dominated natural and applied science investigations in the Western world, to the extent that many engineering educators may not be familiar with any other paradigm. Therefore, it is important to highlight that the qualitative tradition emerged as a countermovement to positivism in the late 19th century and has become a respected and widely used inquiry paradigm in the last half of the 20th century (Glesne & Peshkin, 1992; Creswell, 1994; Ely et al., 1991).

Emerging initially out of roots in anthropology and sociology, the qualitative tradition has proven valuable and unique in its ability to investigate research topics inaccessible to traditional quantitative norms. The qualitative tradition also allows interpretations and meanings to emerge, answering questions of 'why', that quantitative inquiry cannot provide (Taylor & Bogdan, 1998). In doing so, the qualitative tradition has established its own set of norms that govern how research is carried out. While qualitative methods may appear foreign to the quantitative researcher, they ensure that the researcher engages in a systematic, rigorous inquiry of sufficient depth and commitment into the subject matter. This ensures that the researcher can extract real meaning from the participants and develop credible interpretations and theory (Creswell, 1994; Taylor & Bogdan, 1998).

In the following sections, the qualitative design used in this research is described. The description is supported by literature on qualitative methodology that provided a framework for the research and additionally highlights salient contrasts to quantitative research designs. Following an overview of the qualitative design generally, specific protocols and procedures used in the research are outlined in the latter part of the chapter.

Theoretical Perspective

Assumptions

A critical element of a qualitative study is for the researcher to articulate a theoretical perspective out of which the research is being conducted. This requirement acknowledges that inquiry is never free of values (Lincoln & Guba, 1985; Taylor & Bogdan, 1998), but rather that "'facts' and 'values' are inextricably linked. Valuing is an intrinsic part of the evaluation process, providing the basis for attributed meaning" (Guba & Lincoln, 1989, p. 109). The current study was not explicitly identified with any one theoretical framework, but drew on two approaches in particular.

An assumption of the study was that certain questions are critical to develop an understanding of teaching and learning design. The questions of interest to the study, as articulated in the research questions (Chapter 1) and the interview guides resonate with some of the questions of interest to a symbolic-interactionist perspective. These questions include how people define themselves, others, their settings, and their activities; how people's perspectives develop and change; the fit between different perspectives held by different people; and, the fit between one's perspectives and one's activities (Taylor & Bogdan, 1998).

A second assumption of the study was the importance of examining how the roles, responsibilities, and objectives of the various groups of participants in engineering design education related to the overall structure of engineering design education. This assumption resonates with the interests of a structural-functional perspective, as it relates to the overall relationships between participants and their activities. A structural-functional perspective is guided by the assumption that society is a complex system whose parts work together to promote stability (Macionis, Nancarrow Clarke, & Gerber, 1994). Different kinds of social structures (relatively stable patterns of social behaviour) are linked together in terms of their social functions. In simple terms, structural-functionalism asserts that each structure in society has a function, and this function promotes the stability of the whole. Functions are both manifest (intended and recognized) and latent (unintended and unrecognized) (Macionis et al., 1994). Individuals in the society select their activities and actions based on the functions of these activities and actions in promoting overall goals of stability and function within their personal context in society.

Structural-functionalism is deemed a macro-level approach, dealing with society as a whole. In this research, the broad elements of structural-functionalism were assumed to operate in the setting in which engineering design education takes place, i.e. the university. The university is conceptualized as a microcosm of larger society and is itself characterized as a complex system with different social and institutional structures. These structures are linked in terms of their social and institutional functions, and the institutional actors choose activities based on the social and institutional functions and effects of those activities in promoting stability. The positivist or empiricist roots of structural-functionalism (Creswell, 1994; Macionis et al., 1994) also resonate with the general theoretical perspectives of the actors involved in engineering design education: faculty, students, and practitioners whose personalities and formal education as engineers often reinforce positivist modes of thinking. The theoretical frameworks of symbolic-interactionism and structural-functionalism that are reflected in the questions of interest to the study and the institutional context of the study, respectively, are nonetheless distinct from the use and development of theory in the study itself.

Role of Theory in the Study

Taylor & Bogdan claim, "a good qualitative study combines an in-depth understanding of the particular setting investigated with general theoretical insights that transcend that particular type of setting" (1998, p. 26). While the development and verification of theory have been explicit purposes of quantitative inquiry since the outset, the role of theory in qualitative inquiry is somewhat disputed. Different theorists put forth different options and positions; while most agree that qualitative inquiry has a role in *developing* theory, the role of qualitative inquiry in *verifying* theory is more contentious (Glesne & Peshkin, 1992). Another contrast between the paradigms relative to the role of theory is the placement of theory in the study. While quantitative inquiry will begin with *a priori* theory (concepts and hypotheses), theory in qualitative data may be positioned at multiple points in the study, depending on the qualitative approach and method used. Phenomenological and ethnographic approaches that use participant observation techniques for data collection generally derive and position theory late in the study. More structured qualitative approaches, such as interview techniques, may begin with tentative constructs and frameworks, which the study then develops and elaborates.

The dominant form of theory used in this study was the conceptual framework. A tentative conceptual framework for engineering design education was proposed early in the study (see Chapter 2). Congruent with a qualitative paradigm, this conceptual framework was subject to modification and elaboration as the study proceeded. A conceptual framework has been defined in various ways, including "descriptive categories…placed within a broad structure of both explicit and assumed propositions" (Denzin, 1988, quoted in Glesne & Peshkin, 1992, p. 21). Another definition of conceptual framework is "an [explanation], either graphically or in narrative form, [of] the main dimensions to be studied – the key factors, or variables – and the presumed relationships among them" (Miles & Huberman, 1984, quoted in Creswell, 1994, p. 97). The latter definition resonates most strongly with the formulation and intent of the conceptual framework presented in Chapter 2.

The process of conceptual framework development in Chapter 2 followed, to some extent, the guidelines for conducting theoretical inquiry into curriculum as articulated by Grove & Short (1991). The guidelines are to first, define the scope and boundaries of the curricular phenomena or process to be conceptualized (engineering design education); second, discern, assert, and justify the key elements and their relationships which together are used to define the whole (the proposed conceptual frameworks developed in Chapter 2); third, to transform the scheme into a level of discourse appropriate to its use in a specific context; and fourth, to critique and evaluate the conceptual scheme that has been created for clarity, consistency, completeness, persuasiveness, and fit with reality. The initial development of the conceptual framework of engineering design education was intended to be in a level of discourse accessible to audiences in education and in engineering. The remainder of the research investigated participants' perspectives of engineering design education, with a view toward fulfilling the fourth guideline of critique and elaboration of the initial conceptual framework. The following sections outline the data collection and data analysis methods used to fulfil this objective.

Data Collection Methods

In order to access the feelings, attitudes, and perceptions of participants relative to engineering design education, the research used a combination of in-depth (one-on-one) interviews with individual participants and focus groups interviews with groups of participants. The following are general descriptions of the qualitative interview methods used. Additional specific protocol used are described in later sections.

In-Depth (One-on-One) Interviews

One-on-one in-depth interviews were conducted with DT instructors, the NSERC Design Engineering chairholder, and industry cooperators of the DT. The in-depth interview is described as flexible and dynamic, often referred to as nondirective, unstructured, nonstandardized, or open-ended interviewing. In-depth interviewing entails more than one face-to-face encounter with any given participant and is directed toward understanding participants' perspectives in their own words. The in-depth interview is often modelled after a conversation between equals, and is distinctly different from a structured interview, questionnaire, or formal question-and-answer exchange (Taylor & Bogdan, 1998; McCracken, 1988).

In-depth interviewing is considered a strong technique when research interests are relatively clear and well defined. It is also considered a strong technique when the interviewer is interested in understanding a broad range of participants and when time constraints are imposed on the study (Taylor & Bogdan, 1998). Both of these conditions existed in this study, as it was part of the structured graduate program of the researcher.

Procedures for in-depth interviews included audio-taping of each interview (with the participants' consent) and subsequent transcription of the audiotape. Written notes taken by the researcher during the course of the interview supplemented the transcript. The written notes were intended to capture non-verbal features of the situation absent from the audio tape, such as setting, atmosphere, body language, gestures, facial expressions, and thematic turning points in the conversation. The final written transcripts were word-processed in a format conducive to data coding (relative to line spacing, margins, etc.) (Taylor & Bogdan, 1998).

In the in-depth interview situation itself, the researcher worked to maintain a natural and relaxed physical setting and atmosphere, in which the researcher and participant related to one another on a personal and conversational level. The interviewer followed qualitative interview norms of remaining non-judgmental of participants' comments, letting participants speak, paying close attention, and remaining sensitive to the content and direction of the discussion. In-depth interviews began with general topics and themes and gradually moved toward specific questions and areas of focus, using probing strategies to uncover and clarify meanings and perspectives of interest to the research (McCracken, 1988).

Focus Group Interviews

Focus group interviews were conducted with the students of the DT courses. The focus group is a formal approach to group interviewing, in which the researcher brings together groups of people to discuss their perspectives, ideas, and experiences in open-ended discussions. Similar to in-depth interviews, the approach is relaxed, conversational, and non-directive. Focus groups are also designed to use the dynamic of the group to yield insights that may not be accessible without the kind of interaction found in a group (Taylor & Bogdan, 1998; Krueger, 1988).

A focus group can be defined as "a carefully planned discussion designed to obtain perceptions on a defined area of interest in a permissive, non-threatening environment. […] Group members influence each other by responding to ideas and comments in the discussion" (Krueger, 1988, p. 18). Key characteristics of focus groups include a group size of seven to ten people, with an acceptable range of four to twelve participants. Ideally, these participants are a reasonably homogeneous group with certain common characteristics, but who are unfamiliar with each other. The group process is a data collection procedure as opposed to a procedure intended for decision-making, for consensus, or to provide recommendations. The type of data produced is qualitative, in that participants provide insights into their attitudes, perceptions, and opinions. Within the discussion, the topics are carefully predetermined, sequenced, and placed in a context that is understandable and logical to participants (Krueger, 1988).

Focus groups are considered an appropriate technique to provide insight into *why* people think or feel the way they do. It is an appropriate procedure to use when the goal of the research is to explain how people regard an experience, idea, or event by providing their feelings, attitudes, and perceptions. It is also considered a strong technique when time constraints do not allow individual interviewing of everyone in the group, and when the researcher's interest is limited to specific topics not including the private aspects of participants' lives. Planning and design of new programs and evaluation of existing programs are appropriate contexts for focus group applications (Taylor & Bogdan, 1998;

Krueger, 1988). The characteristics of this research resonated with these criteria and made focus group interviews an appropriate data collection technique to use.

Specific advantages of the focus group methodology include its inherent flexibility in allowing the moderator to probe and explore unanticipated issues; its high face validity; its relatively low cost; its ability to produce relatively quick results; and its allowance for increased sample sizes in qualitative studies (Krueger, 1988).

Procedures for focus group interviews included the researcher acting as group facilitator and moderator of the conversation. This role entailed presenting the questions and guiding the discussion and transitions. The moderator also worked to maintain a relaxed and open atmosphere, remain non-judgemental to participants' comments, and invited both positive and negative perspectives. In addition, the moderator listened closely and used strategies such as probing to clarify and expand on participants' comments.

An assistant moderator was used to take comprehensive notes, including quotable phrases and notes regarding non-verbal aspects of the session (e.g. body language, tone, etc.). The assistant moderator used a coded system to maintain anonymity of the participants and identify the frequency of each person's contribution. This coded system facilitated data analysis in terms of knowing whether a specific comment or perspective was repeatedly raised by one individual or shared more broadly among the participants. The anonymous coded system took the form of the assistant moderator prefacing written notes or comments with an alphabet character corresponding to the participant's seating arrangement in the group. The focus group conversation was audio taped as backup only, and was not transcribed. The tapes were held in a secure location in the researcher's home, in case of the unanticipated loss of the written notes. Data analysis relied on the information as recorded by the assistant moderator.

The assistant moderator was also asked to operate the audio tape recorder. The assistant moderator's physical presence was designed to be as unobtrusive as possible. The assistant moderator was selected as someone unfamiliar to the focus group participants but familiar with qualitative inquiry procedures. A personal friend of the researcher, a nurse who recently completed a Master of Nursing degree which included experience in qualitative research methods acted as the assistant moderator in this study.

Common Methods

While in-depth interviews and focus group interviews are distinct techniques with unique characteristics and requirements, some of the data collection methods were common to both. Well-planned, well-sequenced, and well-phrased questioning formed the basis of solid data collection in both types of interviews (McCracken, 1988). Questions were designed to put the participant(s) at ease, to establish rapport between the interviewer / moderator and the participant(s), to direct the conversation, and to probe at the feelings, attitudes, and perceptions that underlie participants' positions or opinions on engineering design education. General strategies in designing a questioning route included using open-ended questions, avoiding dichotomous questions, and beginning questions with 'how' or 'what' instead of 'why'. Interviews began with general questions and left specific or focussed questions for the later stages of the session and/or for later sessions. Questions were placed within a setting or context of background information for the participants (Taylor & Bogdan, 1998; McCracken, 1988).

For both in-depth interviews and focus group interviews, interview guides provided starting points of conversation. The interview guides were not shared with the participants, although participants were given a few days' notice prior to each interview session of the general topics to be covered in the respective session. During the interviews, the researcher did not read from the interview guides nor use them as structured checklists. The interview guides were used as an unobtrusive prompt to channel and guide the conversation, to ensure that consistent categories of data were being covered, and to allow the researcher to focus on the participants' comments.

The data collection techniques outlined above did not preclude commitment to the qualitative inquiry norm of allowing for an emergent research design and emergent analysis during the data collection phase of the research, which may subsequently have affected further data collection strategies. While the overall original design proved effective in this study, participants' comments in early interviews led to additional questions that were added to the interview guide for later sessions. In addition, practices for conducting interviews and focus groups were consistent with qualitative inquiry norms as found in the literature (e.g. Taylor & Bogdan, 1998; Krueger, 1988). For example, for in-depth and focus group interviews, participants were apprised of the context, motive, and intention of the researcher and the research, given assurance of confidentiality and provided with details on how confidentiality would be maintained. Participants were also offered opportunities to read and to comment on the transcript of their own interview, were invited to contact the researcher at any time to discuss the research and the emerging findings, and were invited to contact the researcher if they were interested in reading interim and final drafts of the research product.

Data Analysis

Consistent with the differences in data collection between quantitative and qualitative paradigms, data processing and analysis in each paradigm operate on a different set of assumptions or dimensions as well. Lincoln & Guba (1985) review four dimensions of data processing initially proposed by Goetz & LeCompte (1981, referenced in Lincoln & Guba, 1985). These dimensions are deduction-induction, generation-verification, construction-enumeration, and subjective-objective. Deductive analysis begins with theoretically based hypotheses to be confirmed or rejected; data are defined *a priori* by the hypotheses to be tested or deduced from them. Inductive analysis begins with the data themselves, from which theory and hypotheses are derived by inductive reasoning. Within the second dimension, verificatory inquiry attempts to verify or falsify propositions or hypotheses arrived at elsewhere; generative inquiry attempts to discover theory using the data themselves as a point of departure. Within the third dimension, enumerative analysis uses previously defined units and subjects them to systematic counting or enumeration; constructive analysis is a process of abstraction, whereby units of analysis are derived from the data. Finally, the subjective-objective dimension refers not to the subjectivity or objectivity of the inquirer, but the manner in which conceptual categories are developed. In objective analysis, categories derive from the terms brought to the inquiry by the investigator; in subjective analysis, categories derive from the respondents' own terms (Lincoln & Guba, 1985).

While quantitative data processing will tend to fall to the deduction-verification-enumeration-objective ends of the continua, qualitative data processing tends to be inductive, generative, constructive, and subjective. In contrast to data reduction, the process of data analysis in qualitative inquiry is "essentially a synthetic one, in which the constructions that have emerged (been shaped by inquirer-source interactions) are reconstructed into meaningful wholes" (Lincoln & Guba, 1985, p. 333). Taylor & Bogdan (1998) highlight that working with data in a qualitative paradigm is not a mechanical or technical process, but rather one of intuition, inductive reasoning and ongoing theorizing. This process entails three distinct activities: ongoing discovery, coding the data, and discounting the findings.

Ongoing discovery occurs during the simultaneous processes of data collection and data analysis. It involves the researcher becoming intimately familiar with the data and beginning to identify emerging themes and developing concepts. During ongoing discovery, the researcher wrote analytic memos, constructed preliminary typologies or classification schemes in order to identify conceptual phenomena and their relationships, and developed preliminary concepts and propositions.

Coding the data is a way of developing and refining interpretations of the data, and occurs after data collection is complete. It involves bringing together and analyzing all the data relative to major themes, concepts, and propositions. The constant comparative method initially described by Glaser & Strauss (Lincoln & Guba, 1985) as a data coding method,

> combines inductive category coding with a simultaneous comparison of all social incidents observed. As social phenomena are recorded and classified, they are also compared across categories. Thus, the discovery of relationships, that is hypothesis generation, begins with the analysis of initial observations, undergoes

continuous refinement through data collection and analysis process, and continually feeds back into the process of category coding. As events are constantly compared with previous events, new typological dimensions, as well as new relationships, may be discovered (Lincoln & Guba, 1985, p. 335).

Both Taylor & Bogdan (1998) and Lincoln & Guba (1985) provide specific suggestions for the researcher on which to base a coding or constant comparative process. These suggestions were considered in the research. However, the specific method of coding and comparison also emerged and developed as the research proceeded.

Finally, discounting the data involves interpreting or considering the data in the context in which they were collected, or an assessment of the credibility of the data. Taylor & Bogdan (1998) suggest that an informal review of the data and asking oneself certain questions should be sufficient for most researchers. The questions centre on considering the extent to which data is based on solicited vs. unsolicited comments, the role of the researcher in the setting, and the effect of other participants' presence in the setting. The researcher must also consider direct vs. indirect data, member checks, and an acknowledgement of one's own perspective of the research components. Other writers have provided more extensive discussions on assessing the credibility of data (Guba & Lincoln, 1989; Ely et al., 1991; Creswell, 1994; Glesne & Peshkin, 1992), and this research followed those propositions as summarized in the section *Trustworthiness or Evaluation Criteria*.

Trustworthiness or Evaluation Criteria

A major concern in any research design is the trustworthiness of the design itself and the results it has yielded. Evaluating the quality and credibility of the data, or discounting the data, is a distinct step of data analysis (Taylor & Bogdan, 1998). In quantitative research paradigms, the rigour of the research is assessed by evaluating the design and the results for their 'validity' and 'reliability'. Ensuring a sufficient degree of rigour in a quantitative design entails the use of data collection instruments with proven validity and reliability, physical or statistical control of extraneous variables, random subject selection, and random subject assignment to treatments (Hittleman & Simon, 1997; Jaeger, 1997).

Within the qualitative tradition, 'validity' and 'reliability' are replaced with the terms 'credibility', 'transferability', and 'dependability' of the design and the results. In the qualitative paradigm, trustworthiness encompasses the extent to which conclusions and implications are meaningful for subjects, or the match between the realities of the subjects and how the researcher has presented them. It also encompasses the hypotheses, theories, or inferences that researchers draw from the data and the extent to which other researchers have made similar or different conclusions. It encompasses the perceived fit between what was recorded as data and what actually occurred in the setting, and the technique for documenting the logic of decisions regarding the process and method (Guba & Lincoln, 1989; Ely et al., 1991; Bogdan & Biklen, 1998).

The credibility of qualitative inquiry parallels the concept of internal validity in quantitative inquiry. Credibility is enhanced by a combination of factors, including

- Prolonged engagement (spending an adequate amount of time on the study);

- Persistent observations;
- Using peers and colleagues for debriefing and checking;
- Negative case analysis (seeking out and pursuing alternative explanations);
- Continual alertness to one's own biases and subjectivity as the researcher;
- Member checks (inviting feedback from subjects, or sharing the interpretative process with subjects); and,
- Triangulation (the use of multiple methods and sources for data collection) (Guba & Lincoln, 1989; Ely et al., 1991; Creswell, 1994; Glesne & Peshkin, 1992).

The first two factors were addressed by planning the study over a period of almost one year, in which a thorough literature review was carried out, a preliminary conceptual framework was developed, and the researcher made preliminary inquiries of potential participants to assess their willingness to participate in the study. The subsequent data collection period was deliberately planned to span six months, in order to capture the entire academic term in which the DT courses were taught, and in order to allow participants to reflect on the subject matter between interviews.

Progress checks with the researcher's thesis committee, discussions on the research design and emerging findings with the focus group assistant moderator and another graduate student were instrumental in enhancing the credibility of the research, through peer and colleague debriefing, checking, and negative case analysis. The researcher's own biases and subjectivities were kept in check by reflecting on their scope before data collection started (see section *Role of the Researcher* following), and concerted effort to recapitulate and re-phrase the comments of participants in interview sessions. This also served as part of member checking.

In addition, member checking included returning transcripts of interviews or focus groups to the participant(s) on whom the transcript was based, beginning the next interview or focus group by explicitly asking whether the participant(s) had any concerns about the transcript or any additional comments to make, summarizing the previous interview or focus group at the beginning of the next interview or focus group, and inviting final comments from the participant at the conclusion of the final interview or focus group. All participants were also invited to contact the researcher at any time for updates on the progress of the research, to discuss emerging findings, or to access drafts of the research product.

Triangulation was addressed by using three distinct groups of participants involved in the DT courses (instructors, students, and industry cooperators) and using parallel interview guides for each group of participants. Data also included written documentation provided voluntarily by participants (such as course outlines and course notes), and the researcher attended the final course presentations in which students presented their design projects to the university community.

The transferability of qualitative inquiry parallels the term external validity in quantitative inquiry. Transferability is likewise enhanced by a combination of factors, including:

- Thick description (setting out all the working hypotheses and providing extensive and careful description of settings and contexts, in order to provide the research consumer with as complete a protocol as possible to replicate the study in another setting. This includes full factual documentation and apparent logic of observations and analyses); and,

- A statement of limitations (Guba & Lincoln, 1989; Ely et al., 1991; Creswell, 1994; Glesne & Peshkin, 1992).

This chapter (Methodology) and the following chapter (Findings) have been written with the need for detail in mind: detail in order to allow other researchers to understand the protocol and potentially duplicate the study in another setting, and detail in description enhanced by the participants' own words. A statement of limitations is also included in a later section of this chapter.

The dependability of qualitative inquiry parallels the term reliability in quantitative inquiry. Several factors influence dependability, including

- Use of an established and documented process;
- Stating one's own central assumptions and positions (theoretical perspective);
- Providing detailed and logical protocol for data collection; and,
- Providing an accurate and comprehensive data set (an abundance of evidence) (Guba & Lincoln, 1989; Ely et al., 1991; Creswell, 1994; Glesne & Peshkin, 1992).

The factors enhancing the dependability of this study have been addressed in this chapter, by description of a rigorous and established qualitative research method, articulation of the researcher's theoretical perspective, a detailed data collection protocol, and a comprehensive data set. The data set is kept confidential and held in a secure location at the researcher's home; however, an abundance of participants' own words have been included in Chapter 4 (Findings).

Role of the Researcher

A defining characteristic of qualitative research is the researcher's role as the primary instrument for data collection and analysis (Hittleman & Simon, 1997; Creswell, 1994). By corollary, a key concern in qualitative research is for the researcher to be aware of and able to articulate her own biases and perspectives relative to the subject matter, and to actively work against imposing them on the data collected from participants. Thus, it is appropriate to outline my own background as it relates to the study.

An undergraduate education in engineering and professional practice in engineering have left me familiar with, accustomed to, and comfortable with viewing the world through the paradigms of natural science. Only relatively recently have I been consciously introduced to qualitative modes of inquiry and begun to appreciate their contributions to knowledge and interpretation. In relation to the research focus, my professional experience as a design engineer gives me a perspective of what engineering design is in practice and how the university could relate to that perspective as it provides engineering design education. In addition, I brought existing relationships with some of the participants, primarily of a professional but also of a personal nature, to the research. McCracken (1988) highlights both the positive and negative aspects of the researcher as the primary research instrument, particularly when working within one's own 'culture':

> It is by drawing on their own understanding of how they themselves see and experience the world that they can supplement and interpret the data [...]. Just as

> plainly, however, this intimate acquaintance with one's own culture can create as much blindness as insight (p. 12).

The volume of literature on engineering design education written from a quantitative perspective make a primary purpose in this study to contribute to knowledge and practice in this field by adopting the lesser-used qualitative perspective to address gaps in knowledge about learning design. While lesser-used, the qualitative perspective brings history, rigour, and credibility so as to contribute meaningfully to the field. Personal goals in carrying out and writing this study were to present the methodology in such a way as not to negatively bias nor alienate the participants. Rather, I hoped to use the study to strengthen relationships with those within my chosen profession. These observations and acknowledgements combined to create a personal perspective that I brought to the study.

Specific qualitative norms relative to collecting and working with data can address the personal perspectives or biases of the researcher. These norms included keeping an interviewer's journal and writing analytic memos during the research process. The interviewer's journal contained an outline of topics discussed in each interview, preparation notes for upcoming interviews, and notes of emerging themes, interpretations, or hunches in the data. The journal also contained non-verbal expressions essential to understanding the participants' words.

Analytic memos are a method with which to regularly stand back from the data and record what one is learning. Analytic memos included summaries of major findings of the study to date, comments on specific aspects of the study, and strategies for additional data that may need to be collected (Taylor & Bogdan, 1998). Finally, well-planned questions with disciplined and defined prompting procedures invited the participant to articulate and elaborate what otherwise the researcher may have taken for granted. This was another method by which the researcher established some distance from personal interpretations and perspectives (McCracken, 1988).

The previous sections of this chapter have laid out the theoretical perspective, qualitative data collection and analysis methods, trustworthiness criteria, and the role of the researcher in the study. The discussion has been supported by literature and has described the methods used in general terms. The remainder of the chapter provides a more detailed articulation of the specific settings and protocols used in the research, beginning with a discussion of a pilot study already completed.

Pilot Study

A pilot study was conducted in January, 2002 to April, 2002, as part of a course-based research project, in order to test a part of the design for data collection. In-depth one-on-one interviews of one hour each were conducted with five participants, using the interview guide developed for DT instructors. The participants were all current or former engineering design faculty in the Faculty of Engineering at Western Canadian University, in either an instructor and/or a consultancy role to students. Participants were chosen based on their first-hand involvement in engineering design education; however, none of the participants in the pilot study were participants in the thesis research. Interviews were audiotaped and transcribed. Transcripts were augmented with written notes related to non-verbal features of the interview situation, including setting, tone, atmosphere, and body language; transcripts were also returned to participants for review and comment.

Data were analyzed for interpretations and themes related to participants' definitions of engineering design, goals and strategies for teaching design, and self-concepts as design instructors.

The pilot study provided rich opportunities to practice interview techniques, including the logistics of arranging interviews, formulating questions, questioning and probing techniques, and follow-up procedures. The pilot study also provided opportunities to engage in data analysis, including creating transcripts, analyzing data for themes and concepts, and sharing the analytical process with the participants. A further contribution of the pilot study was to highlight important features in carrying out qualitative research. These features included, for example, the importance of probing for meaning rather than assuming meaning, and the discipline to engage fully and deeply in the data during analysis. At completion, the pilot study yielded rich results and provided a complex, if rudimentary, picture of issues surrounding engineering design education for the five participants.

A separate pilot study of the focus group methodology was not planned. A degree of pilot testing of this part of the methodology was accomplished by having researchers familiar with qualitative inquiry review the planned questioning route. Attention was placed on the logical and sequential flow of questions, the nature of the questions in relation to the characteristics of the audience, and the potential ability of the questions to elicit the information desired (Krueger, 1988). This was accomplished by review of the methodology by the researcher's thesis committee, the process of defending the proposal to a larger audience, and Research Ethics Board review of the protocol prior to implementation.

Secondly, the first of six planned focus group sessions with the DT students also served as a pilot study. The researcher remained open to significantly modifying the focus group procedure based on the first session, and then the first session would not have been included in later analysis. However, no major changes to methodology appeared warranted, the first session was included in analysis.

Research Site

The research site was in the Department of Biosystems Engineering, Faculty of Engineering, Western Canadian University (a pseudonym) in a large Canadian city. The city has a population of over 600,000 and is a key Canadian centre for various industries that require engineering design expertise, including aerospace, agriculture and agribusiness, transportation, and manufacturing. At the post-secondary level, the city is home to three universities and numerous colleges and technical centres.

Western Canadian University offers undergraduate and graduate degrees in arts, sciences, and numerous professional fields. It is categorized as a large Canadian research-doctoral institution. The University operates on two campuses and serves a total student enrolment (undergraduate and graduate) of approximately 25,000 in 2002-2003.

The research focused on a course trilogy in engineering design offered in the Department of Biosystems Engineering in the Faculty of Engineering. The courses are identified by course numbers 34.258 (Biosystems Engineering Design Trilogy I), 34.358 (Biosystems Engineering Design Trilogy II), and 34.458 (Biosystems Engineering Design Trilogy III). The Faculty of Engineering is the only engineering faculty in the province. The Faculty offers six undergraduate programs: civil, manufacturing, mechanical, electrical, computer, and biosystems engineering. All of these programs offer either cooperative work terms or industrial internship options for undergraduate students. All programs are fully accredited by the Canadian Engineering Accreditation Board, with the exception of manufacturing engineering. Manufacturing engineering is a new department in the faculty and is awaiting accreditation results in June, 2003.

The Faculty of Engineering enrolled approximately 1007 undergraduate students in the 2002-2003 academic year. This enrolment has remained relatively consistent over the last five years. Biosystems Engineering enrolled 40 undergraduate students in the 2002-2003 academic year, of which 48% were female (personal communication, Communications Specialist for the Faculty of Engineering, October 2, 2002).

In January 2001, the Faculty of Engineering was awarded an NSERC Design Engineering Chair. The Chair provides $1 Million in federal funding to the Faculty of Engineering and charges the chairholder with developing and implementing initiatives to enhance the presence and effectiveness of engineering design education within the Faculty. The NSERC Design Engineering Chair has facilitated the creation of a Design Engineering department within the Faculty. This department does not offer a separate degree program per se, but rather facilitates the development of existing and new design education within existing departments and establishes concrete links with design expertise in industry. It is within the context of the Design Trilogy courses (DT) in the Biosystems Engineering department and the Design Engineering department that the research was situated. The participants from these departments are described in the next section.

Selection and Recruitment of Participants

Useful and effective qualitative inquiry depends on the selection of an appropriate and adequate sample. In qualitative inquiry, the researcher must remain open to the possibility of changing or adding participants as the study progresses. In addition, qualitative researchers look at settings and people holistically rather than as individual variables (Taylor & Bogdan, 1998).

In contrast to norms of quantitative inquiry in which random sample selection is critical to the validity of the research (Hittleman & Simon, 1997), this research used purposeful sampling (Bogdan & Biklen, 1998). In purposeful sampling, the researcher selected and approached participants and requested their participation in the study, based on some familiarity with the participants in terms of their area of expertise, willingness to participate, and their ability to contribute to the goals of the study. In this study, four distinct groups of participants were identified. These groups of participants were identified as those most intimately involved in the DT courses. Each group of participants outlined below is a primary participant in the DT courses, either as learners, as instructors, as program director, or as industry cooperators of the courses. Prior to recruitment of any participants, the research protocol was approved by the university Research Ethics Board, and the consent of the department head of the Biosystems Engineering department was secured.

1. Students of the DT courses. The researcher engaged in two focus group interviews of one-hour duration with each of the three classes involved in the DT (six focus groups total). The classes encompassed the second, third, and fourth

years of the four-year undergraduate degree program in Biosystems Engineering and are identified by course numbers 34.258, 34.358, and 34.458.

The focus group interviews were scheduled for September and November, 2002, to capture the beginning and end of the academic term in which the DT courses were offered. In collaboration with individual course instructors, the researcher attended a portion of the second lab period of the term in order to introduce herself to the students, briefly describe the research, and request their participation in two focus group sessions. While the introduction was made during a DT lab period, the researcher emphasized that participation in the focus group was in no way related to the coursework for the DT course. A preliminary letter was distributed to all students during the initial introduction, for them to indicate an initial expression of interest and to provide contact information.

To those students who expressed interest in participating in focus group sessions (varied 6 to 7 per class), the face-to-face introduction and preliminary letter were followed up with a second letter. The second letter outlined the context, purpose, and nature of the research and formally requested their participation and written informed consent. Sample letters are included as Appendix B.

2. Instructors of the DT courses (course numbers 34.258, 34.358, and 34.458; three people total). The researcher engaged in three in-depth interviews of one hour each with each of the instructors (nine interviews total). The interviews were scheduled for late August, October, and November, 2002, to capture the beginning, middle, and end of the academic term in which the DT courses were offered.

3. The Chairholder of the Faculty of Engineering NSERC Design Engineering Chair. The researcher engaged in three in-depth interviews of one hour each with the chairholder. The interviews were scheduled for late August, October, and November, 2002, to capture the beginning, middle, and end of the academic term in which the DT courses were offered.

Due to the time constraints of a graduate program of study, it was deemed appropriate to assess the viability of the research by assessing the willingness of the above-referenced participants to participate prior to official recruitment. In June 2001, written communication was forwarded to each of the DT instructors, the department head of the Biosystems Engineering Department, and the NSERC chairholder. The memo outlined the researcher's program of study and research topic, and benefits of the project to the department. The key purpose of the communication was to assess potential participants' interest in the project. Follow-up verbal conversations with each of the potential participants indicated ready willingness to participate in a qualitative data-collection procedure.

In August, 2002, researcher initiated personal contact (phone and/or e-mail) with the DT instructors and the NSERC chairholder to re-establish contact and to outline the nature of the study. This personal contact was followed by a formal letter to each participant, outlining the context, purpose, and nature of the research and formally requesting their participation and written informed consent. A sample letter is included as Appendix B.

4. Industry cooperators of the DT courses (two cooperators per course in each of three courses). The researcher engaged in one in-depth interview of one-half to one hour with each of the industry cooperators.

Industry cooperators participate in the DT courses (34.258, 34.358, and 34.458) by providing real-life design projects from their respective industry to the students of the courses. The design project is presented as an open-ended problem, and the students derive a design solution to present back to the cooperator at the completion of the course.

The department head of the Biosystems Engineering department was requested to make contact with six industry cooperators to obtain their consent to have the researcher contact them regarding their potential participation in the study. The department head delegated this task to one of the DT instructors, and the DT instructor provided the researcher with a list of industry cooperators who consented to be contacted regarding the study. One industry cooperator was involved in two DT courses. The researcher initiated personal contact (phone and/or e-mail) with the industry cooperators to introduce herself, outline the nature of the study, and assess their willingness to participate in an interview session. If the industrial cooperator expressed interest, this personal contact was followed by a formal letter outlining the context, purpose, and nature of the research and formally requesting their participation and written informed consent. A sample letter is included as Appendix B. The interviews were scheduled for January 2003, after the end of the DT courses. This allowed time for the industry cooperators to attend the final design presentations by the students and to read and review the final reports provided to them by the students in December, 2002.

Specific protocols for the in-depth and focus group interviews are outlined in a later section, *Protocols for Data Collection.*

Settings for Data Collection

Appropriate settings for the in-depth interviews and focus group interviews were chosen in collaboration with the participants. In-depth interviews with DT instructors, the NSERC chairholder, and industry cooperators took place at their offices or conference rooms at their place of employment (university or otherwise). Focus group interviews with groups of students of the DT took place in a classroom or conference room familiar and easily accessible to the students in the Engineering buildings. Key features of an appropriate setting were logic of the setting, privacy, and an atmosphere (temperature, lighting, noise, etc.) conducive to focussed conversation (Taylor & Bogdan, 1998).

Times for the interviews were chosen in collaboration with the participants. In-depth interviews with individuals were scheduled with primary concern for the participant's schedule. Focus group interviews with groups of students were scheduled with primary concern for maximizing participation. Specific factors influencing participation were to schedule a focus group session on a weekday not including Friday and to choose a timeslot that was free for the majority of students in a given class. Additional considerations were to schedule the focus group immediately before or after other scheduled commitments on campus so as not to necessitate a second trip to the university for the student.

Compensation was not provided to any participants for their involvement in the one-on-one and focus group interview sessions. As an incentive to students to participate in focus group sessions, the researcher provided a meal (pizza or sandwiches) for the sessions that extended over the lunch or dinner hour, and snacks (cookies, donuts) for other sessions.

Protocol for Data Collection

The data for the research was collected by a combination of focus group interviews with students of the DT courses and in-depth one-on-one interviews with instructors of the DT courses, the NSERC Chairholder, and industry cooperators of the DT courses. The general parameters and considerations by which the researcher conducted the focus group interviews and in-depth one-on-one interviews were described in a previous section, *Data Collection Methods.* This section outlines the specific protocol followed.

Two focus group interviews of one-hour duration each were conducted with each of the three classes of the DT (course numbers 34.258, 34.358, and 34.458), for a total of six focus group sessions. The first focus group interview with the third-year and fourth-year cohorts was scheduled for September, 2002. The first focus group interview with the second-year cohort was scheduled for October 2002. The second focus group interview with all three classes was scheduled for November, 2002. The focus group interviews took place in a classroom or conference room in the Faculty of Engineering, familiar to the students. The researcher acted as the interview moderator. Students and the researcher were seated in an inclusive arrangement around a large table. An assistant moderator was present to operate a backup audio-tape recorder and to take comprehensive notes of the interview session, while seated to the side of the main group. Prior to the beginning of the session, the researcher and assistant moderator set up refreshments on the table for the participants to access at any point during the session.

At the beginning of the session, the researcher re-introduced the context and nature of the research, provided assurances of confidentiality of responses, and informed participants of their right to withdraw from the study at any time. The researcher also introduced the assistant moderator, explained the coded system by which comments were recorded, invited students to take refreshments, and proceeded to engage students in the research subject. The questioning route followed a pre-determined interview guide, included as Appendix C. The researcher remained attentive to the time, guided the discussion using the questioning areas and probes on the interview guide, encouraged contributions from all participants, monitored the atmosphere of the discussion, and noted questions for future follow-up. At the end of each interview session, the researcher thanked participants for coming and invited participants to contact her for follow-up conversations. Subsequently, the researcher and assistant moderator debriefed the session once all student participants had left the room.

The protocols for in-depth one-on-one interviews with individual participants were similar to one another. The researcher engaged in three in-depth interviews of one hour each with each of the three instructors of the DT courses (nine interviews total). The interviews were scheduled for late August, October, and November, 2002. The researcher also engaged in three in-depth interviews of one hour each with the NSERC Chairholder. The interviews were scheduled for late August, October, and November,

2002. Finally, the researcher engaged in one in-depth interview of one-half to one hour with each of six industry cooperators of the DT courses. The interviews were scheduled for January and February 2003.

The interviews took place in the office or conference room of the participant. The researcher provided equipment to audio-tape record the interview, and set up the equipment and positioned it to be as unobtrusive as possible. In addition, the researcher took minimal written notes relating to setting, atmosphere, body language during the interview, as well as key points in the interview in case the audio-tape failed. The audio-taped interview was preceded by a few minutes of general conversation in order to establish rapport and create a comfortable atmosphere. Once the formal interview began, the researcher started the recording, prefaced the questioning by thanking the participant for attending, provided assurances of confidentiality, and re-iterated the participant's right to withdraw from the study at any time.

The researcher engaged the participant in a discussion of the research subject. The questioning route followed a pre-determined interview guide, included as Appendix C. The researcher remained attentive to the time, guided the conversation using questioning areas and probes on the interview guide, and noted questions for future follow-up. At the end of each interview session, the researcher thanked the participant for coming and invited the participant to contact her for follow-up conversations. Immediately after the interview, the researcher debriefed the interview in an interviewer's journal, noted questions that were covered, questions that needed to be revisited, and outlined an agenda for the next interview with that participant.

Interviews continued until no new information emerged from the participants, i.e. the researcher was hearing the same ideas repeatedly from a given participant, during the same interview and/or in subsequent interviews. Examples of interview guides for each distinct group of participants are included as Appendix C. The interview guide for each distinct group of participant(s) was broken down further between the total number of sessions (two or three) with the participant or group.

Protocol for Data Analysis

Data collection and data analysis in qualitative research happen concurrently (Taylor & Bogdan, 1998), and thus the protocol for data analysis flowed relatively seamlessly from the data collection tasks. At the completion of each in-depth interview, the audio-tape of the interview was transcribed by the researcher within 48 hours. Pseudonyms were used for all participants and the transcript was identified by a code only. Transcripts were formatted with double-spaced lines and a wide right-hand margin to facilitate later analysis. Transcripts were then returned in electronic format to the participant on whom the transcript was based, and the participant was invited to review the transcript and provide comments. Follow-up conversations were initiated with participants where the researcher lacked clarity or required the participants' interpretation of a response in a transcript. During the period of data collection and generating written transcripts, the researcher also kept an interviewer's journal to track the progress of data collection and to record emerging themes, concepts, and interpretations as they arose.

Upon completion of the data collection tasks, the researcher engaged in the written transcripts and the written notes from the focus group sessions. Data coding was carried out to identify themes and concepts of engineering design education that arose from the contributions of the participants in the research process. The researcher developed and refined a coding system and identified themes and concepts directly on participants' transcripts, as well as on coding templates (summary sheets) developed for that purpose. Examples of coded data are included as Appendix D. Another objective of data analysis was to compare emerging themes and interpretations with the conceptual framework developed in Chapter 2, in order to critique, modify, and further elaborate an appropriate framework for engineering design education.

Where possible, the comments and emerging findings from in-depth and focus group interviews were cross-checked with readily available written documentation related to the courses. This documentation was defined as the research proceeded and included (from the instructors) course syllabi, course notes, and/or copies of assignment instructions. Where available, participant CVs were taken from the University's website. Copies of press releases related to the NSERC Design Engineering Chair were obtained from the Design Engineering department. Submission of written documents to the researcher was an entirely voluntary process. Where a request for documents was made and no response was received, one follow-up request (e.g. by e-mail or during an interview) was made before the non-response was interpreted as the participant's wish not to submit documents related to their involvement in the DT.

Data analysis continued until no new themes or coding categories emerged. During the process of analysis and writing, the participants were invited to contact the researcher at any time to discuss the progress of the research, emerging findings, or read drafts of the final research product. Requests were answered in telephone, e-mail, and face-to-face conversations.

Timing and Length of the Study

Recruitment of participants commenced in summer, 2002, upon the Education/Nursing Research Ethics Board (ENREB) approval of the research protocol and the consent of the Biosystems Engineering department head. A copy of the ENREB approval letter is included as Appendix E. In-depth and focus group interviews took place over a six-month period from August 2002 to January 2003. This period captured the academic term in which the DT courses were offered (September - December, 2002) and all participants were actively engaged in the DT experience. Where more than one interview session was planned with any given participant or group of participants, the sessions were scheduled to capture the beginning, (middle), and end of the academic term in which the DT courses were offered. This schedule allowed the researcher to explore how a participant's views may or may not have changed over the course of the term, and allowed participants to reflect on the research topic between interviews. As per qualitative inquiry norms (Taylor & Bogdan, 1998), data analysis began simultaneously with data collection and extended into winter, 2003. Writing took place between January and March, 2003.

The previous sections have provided details of the specific research site and settings, selection and recruitment of participants, and protocols for data collection and analysis. This chapter concludes with a discussion of the ethical considerations of the research and the limitations of the methodology.

Ethical Considerations

The research used human beings as participants in the research process. However, the participants in the research were not subjected to any experimental treatment or intervention. The primary ethical considerations related to the research included the protection of privacy and integrity of relationships between participants and participant groups.

Due to the power differentials that exist within a university environment between students and faculty, the peer relationships between faculty and department heads, and the professional relationships between the university and the industry community, confidentiality of all participants was a primary ethical consideration in this research. An explicit assurance of confidentiality was made in all formal correspondence to participants and verbally prior to each interview session with each participant or group of participants. Confidentiality of participants was also addressed in the following ways.

In transcripts, notes, and reports, all participants were referred to by pseudonym (in-depth interviews) or coded system (focus groups) only. The coded system took the form of each participant in the focus group being assigned an alphabet character corresponding to their seating arrangement in the group. Students retained the same letter for both focus group sessions. Whether in electronic or hard copy form, transcripts were identified only by a code and were stored in a secure location at the researcher's home. Transcripts were accessible only to the participant on whom the transcript was based and to the researcher's thesis committee members as necessary. Upon the completion of a transcript, audiotapes on which the transcript was based were erased.

In the final writing, all participants are likewise referred to only by pseudonym or coded system. All descriptions, citations, or paraphrases in the writing are short excerpts only and were made generic with respect to organization, industry, gender identification, and unique personal features or identifiers. Such features included but are not limited to participants' name, age, ethnicity, position (other than as identified as one of the four categories of participants), distinctive speech patterns, etc.

Any written documentation related to the course provided by any participant was not shared with anyone beyond its author. Only short excerpts were used as necessary to illustrate results. Upon completion of writing, transcripts and all other documentation were filed at the researcher's home until all articles arising out of the research have been accepted for publication. This period will not exceed five (5) years, after which all transcripts and documentation will be destroyed.

In addition to confidentiality concerns, informed consent of all participants was an important ethical consideration. Prior to engaging in data collection, all participants were given a written letter outlining the context, purpose, and nature of the research and formally requesting their written informed consent as a participant. A participant's signature on a "Consent Form" was taken as informed consent in engaging in one or more interview sessions with the researcher and allowing the data to be used in further analysis and reporting. Sample letters are included as Appendix B.

Limitations of the Methodology

This chapter concludes with a discussion of the known limitations of the techniques and procedures in the research design. Some limitations are inherent in the technique and were not amplified in this research design. Examples of such limitations relative to in-depth interviews include the nature of interviews relative to participant observation and the effects of audio tape recordings of the interviews. Examples of such limitations relative to focus group interviews include the effects of group dynamics. Other limitations arise out of the specifics of the research design. One such limitation relative to focus group interviews includes the use of established (existing) groups instead of groups of strangers. Mitigation strategies were also identified.

Participant observation is seen by some as the normative qualitative data collection method, or the method against which all others are measured (Taylor & Bogdan, 1998). In contrast to the first-hand observations gained through participant observation, in-depth interviews and focus group interviews rely on second-hand (verbal) accounts of participants. Since people act by nature inconsistently, saying and doing slightly different things in different situations, the researcher must be aware that the interview setting is one particular type of situation. What the participants claim as their thoughts and actions may not exactly coincide with their actual thoughts and actions in other situations. Secondly, the limitation of interview methods relative to participant observation is said to be the researcher's lack of context necessary to understand many of the perspectives that emerge. This limitation may manifest itself in different ways. The researcher may be likely to misunderstand participants' language (vocabulary and terminology) and participants may be unwilling or unable to articulate things that could have been observed through direct observation. Mitigation of these potential limitations included spending a sufficient amount of time with the participants to understand what they mean, creating an atmosphere conducive to free and open conversation, eliciting rich description from the participants, and getting to know participants outside of the interview situation (Taylor & Bogdan, 1998).

A second potential limitation of interviews is the conscious or unconscious effect that audiotape-recording of in-depth interviews has on both the researcher and the participant. Taylor & Bogdan (1998) warn that it is naïve to assume that taping will not alter what some people are prepared to say or do; few people want to claim negative or socially offensive views on permanent record (e.g. racism, sexism). Mitigation of this weakness included establishing rapport with the participant through the researcher's presence (presentation of self). In addition, interview questions were planned to put the participant at ease and allow for true meanings and thoughts to emerge in non-defensive and non-argumentative ways. Mitigation also included obtaining consent for tape recording the interview, and placing the tape recorder so as to be as unobtrusive as possible.

An important potential limitation of the focus group interview method is the effect(s) of group dynamics on the data collected. The group dynamic is simultaneously seen as a strength of the method, as influence among group participants is acknowledged and sought after in the focus group strategy. However, the researcher must be aware that participants may not say things in the context of the group that they may have been willing to share in private. In addition, less vocal participants may defer to those who are most outspoken, thus leading to a superficial consensus within the group (Krueger, 1988;

Taylor & Bogdan, 1998). Therefore, it was important for the researcher to have some way of tracking who said what within the group. This guarded against the researcher being faced with an overwhelming amount of data without being able to discern whether the perspectives represented repeated comments by one or two individuals, or truly represented the comments of the majority of the group. The strategy used to anonymously code participants' comments in focus group sessions was presented earlier.

Additional characteristics of focus groups include that the researcher has less control in the group interview relative to the individual interview, personalities of groups can vary considerably, and the logistical difficulties of assembling a group are larger than with individual interviews. Effective leadership and facilitation skills on the part of the moderator are also required for an effective focus group experience. The researcher has taken a significant amount of training in conflict facilitation and group procedures in the past five years, which provided opportunities to learn and practice skills directly applicable to facilitating the focus groups.

Another potential limitation amplified in the research design was the use of established groups (engineering classes) for focus group sessions. The focus group is described as a robust method that allows for minor variations in technique while still yielding strong results (Krueger, 1988). In this research, the participants in the focus group were familiar with one another as they are classmates in more than one course. Considerations of using focus groups for established groups include the need to acknowledge that existing groups may have formal or informal ways of relating that can influence their responses. In addition, it is important to consider whether participants are selective in what they say in front of others in the group. Participants' positions on issues and ideas may reflect a need to relate to other group members in a certain way. Mitigation strategies included holding separate focus group sessions for each cohort (second-year, third-year, fourth-year) in the program. Participants' potential inhibitions based on perceptions of superior-subordinate relationships between cohorts were minimized in this way.

Finally, an essential concern for the researcher in any methodology is the risk of imparting one's own contexts and conceptualizations onto the terms, vocabulary, and comments provided by the participants. The researcher may be particularly vulnerable to this potential limitation when a degree of familiarity exists with the subject of the research, participants, and/or settings, as in this study. Mitigation of this potential limitation relied on the researcher's awareness of the risk, the formulation of well-planned questions, and the researcher's preparation and discipline in probing for meaning and clarification, rather than assuming the same.

The findings of this study are also limited to the research questions and the type of data accessible with the qualitative methodology used. While quantitative research designs seek to generalize research results to the larger population, it should be noted that the findings of this qualitative study apply to the described setting and the described participants at that particular point in time.

This chapter has outlined the qualitative research methodology used to explore engineering design education within one department in the Faculty of Engineering at Western Canadian University. The study used a combination of focus group interviews with students in three engineering design courses and in-depth one-on-one interviews with instructors of the three courses, a program director, and industry cooperators of the design courses to explore these participants' ideas, opinions, and perceptions of engineering design education. The objective of the research was, through inductive analysis, to establish themes, concepts, and propositions related to engineering design education, and to elaborate a preliminary conceptual framework developed for teaching and learning design within an engineering curriculum.

Chapter 4:

Findings

The results of this study revealed a rich understanding of teaching and learning engineering design in a Biosystems Engineering program. This chapter reviews the findings of the qualitative data collection and data analysis processes outlined in Chapter 3 (Methodology). The chapter begins with a profile of the DT courses and the research participants. This is followed by an outline of the findings relative to the research questions, as well as additional themes and findings that arose during data collection and analysis. While this chapter is limited to reporting the data, Chapter 5 (Discussion) relates these findings to the conceptual framework developed earlier, and discusses the implications for teaching and learning.

The primary concerns in presenting the results were maintaining the integrity of the data in how they were presented and interpreted, and protecting the confidentiality of the participants. Wherever possible, verbatim quotations have been used. However, to enhance confidentiality and readability, quotes have occasionally been corrected for grammatical errors and/or modified with respect to specific names or phrases of speech that may identify one individual. All names used in this chapter and the following chapter are pseudonyms. A referencing system is used where quotes are identified by page number on the interview transcript (e.g., Peter, 57). At times where it was deemed preferable due to confidentiality concerns to not even identify a quote by pseudonym, it has been identified by the transcript code and page number (e.g., F3T2, 16). Quotes from students in focus groups are identified by the focus group code and page number (e.g. FG3-1, 4), or by focus group code and letter assigned to a particular participant in the group (e.g. FG3-1, B). This system was designed to provide transparent linkages between the results presented and the raw data.

The General Experience in the DT Courses

Based on discussions with the DT instructors and reviews of the course outlines and other course material (lecture notes, course schedules) for the 2002-2003 academic year, a picture of the DT courses emerged. All courses were four credit hours, and were allotted an 80-minute lecture slot on Tuesdays and Thursdays, and a 180-minute lab slot on Thursdays. The parallel timeslots allowed for instructors to bring all three student cohorts together for joint learning experiences several times during the term.

The first course in the DT, 34.258 (Biosystems Engineering Design Trilogy I), emphasized a base understanding of the Biosystems Engineering department and the engineering profession relative to its history, organization, regulation, and codes of ethics; oral and written communication skills; and, the design process. Other content areas included valuation of engineering services, project planning and control, and safety in design. Students wrote mid-term and final examinations testing content areas, practiced public speaking, and completed design assignments. One significant design assignment was called "Assembly Drawings", which paired students in teams of two. Each team was given a household gadget, disassembled the gadget, and created assembly drawings. The assembly drawings and the gadget pieces were traded with another team, who then re-assembled the gadget based on the first team's assembly drawings. The groups evaluated each others' work in this exercise.

The second course in the DT, 34.358 (Biosystems Engineering Design Trilogy II), emphasized fundamental concepts of safety engineering and human factors engineering. Other content areas included project planning and engineering modelling. Students wrote mid-term and final examinations evaluating content areas and completed design assignments. Examples of design assignments related to safety and human factors were the design and fabrication of a safety shield for a bicycle for physically challenged persons, the design of a piece of personal equipment (e.g. helmet, joystick) in which anthropometrics (dimensions of the human body) were considered, and the design of a fatigue meter.

The third course in the DT, 34.458 (Biosystems Engineering Design Trilogy III) is, in the words of the instructor, "*much* more open-ended and *much* less formal" (F4T2, 50) than 34.258 and 34.358. Content emphases included running a design business, ethics, and professionalism. Other topics included valuation of engineering services, working cross-culturally, ISO certification, and financial reporting. However, content was deliberately left fluid, to allow the instructor "to address anything that happens to come up in the course" (F4T2, 69), and classes were less structured relative to the other two courses. Students wrote one test covering a required reading, attended plant tours, and completed design assignments. One significant design assignment had the students use shop tools (welders, saws, drill presses, etc.) to fabricate components out of different materials (e.g. wood, metal) over the course of five weekly lab periods; the individual components were then assembled into a final product.

In addition to these individual course features, a number of features were common to all three DT courses. In all courses, student teams completed a major design project. The design project was often described by students as "the main component" (FG4-2, 1) of the courses. The expectation relative to the completed project ranged from a conceptual design in 34.258, detailed design with engineering drawings in 34.358, and detailed design, drawings, and economic analysis in 34.458. External industry cooperators attended one of the first classes in the term to introduce the projects from their respective businesses to the students. Students then completed a short proposal relative to which project they would like to work on; instructors assigned project teams and attempted to take students' preferences into account. Students on a given project team were all enrolled in the same course.

Once student design teams were assigned in all three courses, teams for each project met for a joint brainstorming session. Each brainstorming session included three design teams: one from each course. Each team took a turn presenting their project to the other two teams, and then all three teams in the session helped generate ideas for the other teams as well as for their own team. The fourth-year team was responsible for facilitating this joint brainstorming session. In one of the next class periods, the three classes met together and each design team gave a short presentation to the entire group, summarizing their project and their preliminary design ideas and inviting feedback from the other design teams. Out of this session, each person in each class was responsible for completing a short proposal, indicating to which design team they would like to contract their services. An assignment in all three courses was "contracting out", in which every individual was responsible to contract four hours of their services to another design team (in the same class or in another class), to carry out tasks decided by the design team – their 'employer'. Typical tasks included literature reviews and other research, and drafting services. In this way, each student in each class had the chance to be both 'employer' through their design team and 'employee' to another design team.

'Employees' were evaluated by the design team, and 'employers' were evaluated by the instructor.

Different instructors had different expectations relative to what students needed to demonstrate in the design project. For example, one instructor required students to complete a project portfolio, consisting of evidence of having undertaken and reflected on the design process. All instructors required some form of paper trail or job log of the design project, in which students demonstrated their design process. All students also had to submit preliminary design drawings to the Biosystems Engineering shop technicians, and meet with the technicians for their feedback on the students' designs. All instructors required a draft of a final written report to be handed in before the end of the term to allow the instructor opportunity for feedback and comments prior to the required final report. At the end of the term, the three classes came together for the final, public presentations of their design projects and design solutions. After the final oral presentations, all instructors debriefed the presentations with their classes and then privately with each group in their class. In sum, significant class time was allotted to design project activities and group work – generally twelve 80-minute lecture periods and five to six 180-minute lab periods.

Besides the design projects, other learning experiences were also common to the three DT courses. For the first lab session of the term, the classes met together and the instructors planned a design activity to allow students to get to know each other, to integrate the second-year cohort into the department, and to engage students in a fun, low-pressure design exercise. In this year's activity, students were given a ball and were challenged to create a new sport based on the ball's characteristics and several other constraints. Later in the term, all three classes came together for joint lecture on a specialized safety topic by a guest speaker. This year's lecture was related to agricultural fire safety.

The General Experience of the DT Research Participants

To set the general context for the presentation of the results, each group of participants and their overall experiences in the design courses are first presented in overview.

NSERC Design Engineering Chair

Barry is the NSERC Design Engineering Chair at Western Canadian University. His current involvement in the DT courses is arms'-length, although he has been a long-time former instructor of the two courses that evolved into 34.258 and 34.458. In his role in the Design Engineering department, the NSERC Chair supports design education at the departmental level in various ways: introducing Engineers-in-Residence to the undergraduate curriculum to "put people in place who can bring a design understanding" (CT3, 84), facilitating design colloquia on a bi-weekly basis to bring engineering faculty and industry engineers together in discussions related to design, providing resources and profile to bring internationally-known speakers to campus to discuss design, and enabling design co-operation with other local institutions.

Barry is a tenured, full professor at Western Canadian University, having completed undergraduate and graduate degrees in Engineering. After five years in private industry as an agricultural design engineer, Barry's academic career at Western Canadian University has spanned nearly 30 years. Barry's responsibilities consisted of teaching, research, and service in the Biosystems Engineering department for the majority of this time, and more recently included a period as Biosystems Engineering department head and currently as Associate Dean of Design Education for the faculty. Barry is a warm, open, and reflective person who communicates strong commitment to undergraduate education and design education, an interest in knowing students and colleagues, and an interest in new ideas.

DT Course Instructors

To enhance confidentiality, the instructors have deliberately not been identified relative to their course. All three course instructors are male.

Mark is a pre-tenure faculty member (assistant professor), having completed undergraduate and graduate degrees in Engineering. Mark's industry experience includes short periods as an agricultural design engineer after his undergraduate degree, and as a research scientist associated with his Master degree. Mark's prior experience also includes farming. Mark's current responsibilities consist of teaching, research, and service in Biosystems Engineering. Mark is a thoughtful, organized, and self-aware person. He prepared for interview sessions by reflecting on the general topics prior to the interview and jotting brief notes. Mark appears very conscientious in his work, and he communicates genuine interest and concern for the best possible experience for students, with a focus on meaningful learning and graduate preparedness: "to get students…actively involved in their learning" (Mark, 14) and "prepare engineers that are going to graduate…best as possible for what they are going to experience when they leave" (Mark, 13).

Gord is an adjunct faculty member and Biosystems engineer-in-residence. Gord has also completed undergraduate and graduate degrees in Engineering. Gord's engineering career was preceded by an apprenticeship and a decade of work experience in a skilled trade. Other significant experiences in Gord's life and career have included several years' overseas work experience in a developing nation, and ongoing self-employment in an engineering consulting business. Gord's responsibilities at Western Canadian University include teaching and student resourcing in his role as engineer-in-residence. Gord is a warm, flexible, and reflective person who communicates an entrepreneurial spirit. In his academic role, Gord's primary interest appears to be the students' experience, particularly as it relates to non-technical professional competencies and a holistic perspective: "What's your expectation of being an engineer in a global environment? What do you think your role's going to be?" (Gord, 55).

Peter is a sessional instructor in Biosystems Engineer and a full-time professional engineer in private industry. Peter holds an undergraduate degree in Engineering and a graduate degree in Business Administration. Peter's engineering career was preceded by eight years' work experience prior his undergraduate degree. His professional life as an engineer has included sales, agronomist, engineering (design, project management) and managerial roles in agriculture and agri-business. Peter's responsibilities at Western Canadian University are limited to teaching one DT course. Peter is an enthusiastic and open person. He communicates genuine interest in his part-time teaching role and awareness of the skill set required to be an effective teacher. In his instructor role, Peter's primary interest appears to be bringing practical, industry information into the curriculum and preparing students for the realities of industry careers: "I want them to be able to understand what it is to be an engineer in the real world. [Where] they're going, what's going to be expected of them" (Peter, 45).

DT Students

Six students in 34.258, seven students in 34.358, and seven students in 34.458 participated in the focus group sessions. The gender balance (female:male) in the focus groups was 3:3 in 34.258, 2:7 in 34.358, and 4:3 in 34.458. The experiences (and implied ages) of participants ranged from entering engineering directly from high school, entering engineering after completing prior degrees (5 participants), and entering engineering after other jobs or careers (2 participants). Most participants mentioned working hard to balance the demands of engineering studies with other parts of their lives, including employment and family responsibilities.

Co-op work experiences are available to undergraduate students in Biosystems Engineering, consisting of two eight-month work terms. The first work term begins in January of the third-year program. Therefore, students choosing a co-op option have completed 34.258 and 34.358 prior to their first co-op experience. One participant in 34.258 and four participants in 34.358 indicated that they planned to take a co-op option. Four participants in 34.458 indicated that they have completed a co-op option. When asked if and how the co-op experience changed the students' behaviour and performance in 34.458 relative to those in 34.458 that did not have the co-op experience, the instructor indicated that, in his experience, the main difference was in students' exposure to the business side of the work and their inclination to put the course "in the context of their own work experience" (F4T3, 74), such as in student's ability to estimate the value of engineering services.

The focus group participants appeared to be focussed, articulate, and positive individuals. Within the three cohorts, there appeared to be strong bonds in that participants seemed comfortable with one another, respectful of each others' differences, and familiar with each others' situations. The cohorts included outgoing people with much to say in the group, as well as quiet, soft-spoken individuals. However, one strong pattern that emerged was that each individual's comments were thoughtfully considered and demonstrated consistency and integrity across the two focus group sessions.

While not without exception, most participants' overall attitude towards the DT courses was positive: "it's one of the best courses we have" (FG3-1, E) and "it's fun work" (FG2-2, A). Students cited numerous course characteristics as important to their enjoyment of the courses, including the design project; working as a team; smaller classes and informal, collegial relationships with peers and instructors that facilitate bonding within the cohort; allowing students to self-direct work and take responsibility – "they treat you more like an adult" (FG3-1, 4); exposure to hands-on shop experience; and contact to the other cohorts and the related ability to gain confidence in the design process with each course in the trilogy. Industry connections also emerged as an important factor in students' positive experiences in the courses, including instructors' experiences working in industry, design projects' connections to industry, and opportunities to develop industry contacts through the design projects: "you get to step beyond the classroom into the real world" (FG3-1, 4).

Students also had numerous suggestions for the courses (see later sections in this chapter). However, an important overall impression that emerged from their comments and suggestions was the students' motivation for a meaningful, experiential learning experience and graduate preparedness rather than a (perhaps stereotypical) motivation for less work in the courses. Students repeatedly referred to seeking relevance and having contexts in which to place the course content: "we could benefit more from lectures if they were applied to our design project" (FG3-1, 3) and the experiential nature of learning and of design: "you learn by doing; it's pretty hard to be *taught* how to design (FG3-1, E)". Students' comments also expressed regret that the courses were not long enough to take design projects to the hands-on stages of prototyping, testing, and/or fabrication: "the design process gets truncated before we can see the outcome" (FG4-1, 4), and "we'd like to gain insights from the testing process and see the 'oops' of the project" (FG4-1, 4).

DT Industry Cooperators

Six industry cooperators represented seven design projects in the DT courses. All cooperators represented local businesses and locally significant industries. Projects ranged from designing, enhancing, or modifying devices used in agriculture, designing agri-business operations, and modifying common household items to take advantage of local conditions or respond to unique user needs. All cooperators were male.

Dave has been an industry cooperator to the DT for the last three years and represents a small, rural business in the province. Cameron, Matthew, Art, Randall, and Tim have all been industry cooperators to the DT for one year only. Between these five cooperators, two small-to-medium sized businesses and two government-related organizations were represented. Two of the six cooperators are professional engineers, working as engineers and educated as engineers. The other four cooperators come from a variety of educational and professional backgrounds. Educations include skilled trades, technical education, business education, and a Ph.D. in agriculture; professional roles include a skilled tradesperson, a business owner, a marketing professional, and a research scientist.

When asked to reflect on their motivation to be involved in the DT courses as industry cooperators, cooperators cited a variety of factors. Primarily, cooperators referred to the opportunity to move forward on projects that internally, their organizations do not have enough human resources and/or a specific technical expertise to address. Participants saw their involvement as "a way to get a couple of things rolling…because we just have so many projects" (Matthew, 5), and "an excellent opportunity to find out a little bit more about some things, and have somebody else do that" (Dave, 4). Other motivators to be involved in the project centred on the contributions of students: "students are a great source of talent…and a good resource to tap into" (Cameron, 3). The cooperators that had hiring roles in their respective organizations also commented that their involvement was valuable way to get to know and 'pre-screen' potential future employees. One cooperator referred to the large numbers of engineers employed in his organization, and the organization's commitment to "support the university and the students at the university, and groom them for the future" (Randall, 6).

Closely related to personal motivators to be involved were the benefits that cooperators sought out of their involvement. Primary benefits that cooperators hoped to gain included an outsider's perspective and an innovative perspective. As a typical example, Matthew talked about looking for "an outside perspective. I think I'm too close to it all now, and I just can't see the forest through the trees anymore. I was hoping for a whole, new, fresh outlook" (7), and Art referred to getting "stuck in a rut, and you can't see your way out. But somebody else coming in from outside can quite often see something different and give you an idea" (8). Cooperators also spoke of wanting to take the students' work – if only pieces of it – and move it forward within their organization. Cameron hoped to "take pieces of what they came up with and add it to our existing product" (4), Randall referred to the project as a "scoping study" (5), and Dave referred to getting "one more piece of information to add to the lexicon" (4). Beyond theory, though, cooperators were also seeking "a practical way to do it" (Matthew, 8) and input on "how to actually make this work" (Tim, 3).

Overall, industry cooperators characterized their involvement as positive and beneficial, and all cooperators indicated their willingness to be involved in the courses again. For several cooperators, this willingness was qualified with specific recommendations for the administrative logistics of their involvement, including enhanced information on their role and responsibility in the partnership, enhanced communication with the university, and clearer guidelines on what they may expect from the students. These recommendations are dealt with in more detail in a later section of this chapter. However, all cooperators spontaneously indicated that their personal experience should be secondary to the students' experience: "one of my big concerns is being sure that the students actually come away better off than they were to start with, whether *they've* come ahead with this" (Tim, 18) and "it's about the students, not about the companies, and that's the way it should be positioned" (Cameron, 13). It was these kinds of backgrounds and experiences with design and design education that instructors, students, and cooperators brought to more specific aspects of the DT, beginning with how they conceptualized design.

Concepts of Design

Defining Design

When asked to define design, participants often began by indicating the difficulty of the task. Students agreed that design is a "very tough word to define" (FG3-1, C). Barry indicated he doesn't "find that the literature contains the kind of definition of what we do" and that the "profession has not bothered to try and understand it" (12). After qualifying the difficulty of the task, students', instructors', and industry cooperators' responses centred around concepts of problem-solving, creativity, process, iteration, and analysis. All three cohorts of students used the terms 'problem-solving' and 'iterative process' as initial ways of defining design: "design is a variety of problem-solving techniques that apply to diverse situations" (FG3-1, D). Similarly, other participants defined design as "a practical solution to problems" (Barry, 12), "a process of getting from an ill-defined problem to an acceptable solution" (Mark, 11), and "definitely a process…and trying to figure out a real practical way to solve a problem" (Matthew, 6).

While participants were willing to articulate specific components of the design process, participants also stated that the process can be ambiguous: "it is different for each of us, probably is different in different situations" (Mark, 15). Although second- and third-year cohorts also used the term 'creative' or 'creative process' to define design, the fourth-year cohort articulated the process in more defined steps including "brainstorming", "research", "analysis", and "testing" (FG4-1, 1). Instructors delineated the process as including problem identification, project planning, constraint identification, brainstorming, concept development, consultation, analysis, testing, and finally, realization of a final product, process, or system. Industry cooperators were less specific in delineating process components, generally describing "taking a concept or idea and creating a workable product out of it, applying real-life constraints to an idea" (Cameron, 2).

Analysis was mentioned by two student cohorts and by most other participants as a key component of design. Barry described the design process as supported by "instrumentation and analysis" (12), while Gord stated, "design is the process and analysis provides the tools to do the design" (25). Students and instructors held common perceptions of the key constraints to be considered in design. Students mentioned constraints of "time, safety, and cost" (FG3-1, 1). Instructors agreed, and added additional constraints: human constraint of personal abilities, understanding, comfort level, and professional ethics; resource, material, and equipment limitations; consistency with cultural norms or cultural context; and client's visions, needs, and views. Industry cooperators' comments repeatedly emphasized a tangible, working final product as a design parameter: "that's really the proof in the pudding: does it work" (Tim, 10), and "something that will ultimately function at the end of the day" (Randall, 3).

When asked if they expected to design in their professional careers as engineers, the overwhelming majority of students indicated that they expected to or hoped to, and their comments alluded to an emerging understanding of a broader definition of design: "If design equals problem-solving, then design is a part of the human experience" (FG3-1, D) and "a large component is group work, and that's the real world" (FG4-1, C). Instructors and industry cooperators were more explicit in emphasizing a broader context of design that requires consideration and understanding. Mark and Barry referred to design as the entirety of "what engineers do" (Mark, 11; Barry, 16), and to design as "a mindset, the way one reacts to a problem" (Barry, 12). Peter described design as "the whole project; it's broader than technical" (23). Key features of the design context included understanding the value of the other non-engineer participants in the process, such as skilled tradespeople and technicians, contractors, and clients. Dave, for example, highlighted "client's preferences and abilities and looking at the issue of professional liability" (3) as key considerations in design.

On yet a broader level, the NSERC Chair and all DT instructors spontaneously described the act of planning and delivering the DT courses as design, as well as the presence of design thinking in the routine activities of life. Gord mentioned, "virtually every day is a design exercise. Getting the kids out the door before the school bus arrives is a design exercise" (25-26). Mark described course planning in the following way:

> I've never delivered the same course the same way twice. I suppose it goes to the idea of iteration – using the feedback of what happened last year to re-design for the coming year. I don't think I've ever thought of that as a philosophical thing that I was trying to do; it just seemed logical to be doing that (22).

The findings related to concepts of design demonstrated that, in general, instructors and industry cooperators emphasized the final design product to a greater degree in their personal definitions of design than students did. As well, instructors articulated a more developed awareness of social, economic, and functional design parameters than industry cooperators and students did.

Influences on Design Concepts

When asked to consider who or what had influenced their concepts and definitions of design, participants referred primarily to personal experiences and persons in their lives, rather than formal education or coursework in design. In all student cohorts, students spontaneously mentioned family members who are engineers and family backgrounds that included “entrepreneurial types” and “solution-focussed” individuals (FG2-1, C, D). Students also mentioned popular culture such as car commercials and specialty channels (The Learning Channel) as influences on their concepts of design. While second-year students explicitly stated that the DT course was not a large influence on their concepts of design, a transition was evident in that by fourth-year, students readily listed university courses including the DT, co-op work experiences, and fellow students as influences on their concepts of design. The NSERC Chair and the DT instructors all have experience as design engineers outside of the university and continue to identify design activities in their current scope of duties as instructors, researchers, administrators, and consulting engineers. These four participants readily noted the impact of their personal background, industry experiences, and relationships to professional colleagues on their personal concepts of design.

Teaching & Learning Engineering Design

Learning Theories & Approaches to Teaching

The NSERC Chair and the three course instructors were asked to reflect on their approaches to teaching, and the extent to which a particular learning theory or theories guided their work. A number of common elements were identified in the responses of these four participants. Primarily, participants referred to the DT courses as a marked deviation from the analysis and theory courses that dominate the undergraduate curriculum, and as an introduction to industry-like work environments in which industry perspectives are important and where practical, hands-on environments and experiences are planned. Mark described it as "trying to create an environment that is approaching what would happen in industry" (16). A range of components contributed to this teaching approach, including expectations that students develop experience with the design process grounded in a problem provided by industry; experience with shop tools and shop equipment; experience with industry communication formats (reports, presentations, letters); interaction with and feedback from non-engineering professionals such as the shop technicians in the Biosystems Engineering department; and fostering non-technical engineering skills and people skills.

While these factors were common to participants' responses, it was also clear that each course instructor had a unique, personal approach to teaching. Mark's responses focussed on creating an active learning environment: "coming to a realization that a traditional lecture is not my strength, and it's certainly advantageous in the classroom to be doing some different things that can enhance the learning" (21). In outlining the teaching strategies and assignments that he plans for his course (see later sections), Mark highlighted how these strategies and assignments were designed to engage students in the subject matter and have them create their own information. In describing active learning, Mark talked of his role in "providing assistance or cues that help students make the transitions from point A to point B", which includes "as many steps as possible that allow iteration and feedback to occur" (16-17).

In discussing approaches to teaching with Gord, the notion of hands-on experience for students dominated: "it's a case of learning by doing, but it's learning by discovery as well" (49). Gord also referred to trying to stimulate curiosity and accommodate different learning styles and preferences by bringing out the strengths and contributions of each. Gord's responses indicated that students should feel comfortable challenging information and feel entitled to ask 'why': "it isn't acceptable to me to say to someone, 'well, you do this just because'" (3); "explaining 'why' is so important" (41).

While all three instructors agreed on the importance of creating an industry-like environment in the courses and bringing an industry perspective to the courses, Peter's comments seemed to reflect this opinion more strongly than the others. Peter augmented this view by referring to his approach of grounding the course information in his personal industry experiences: "what I can bring to it from my experience or my knowledge base" (37) and giving students hands-on opportunities to practice concepts and activities. These approaches are combined in the classroom, in which Peter "takes students through exactly what we've talked about – the design, how to design – not just the concept, but going through the whole process and highlighting what to look for, what the real world is all about" (30).

In assessing the extent to which the three course instructors' approaches to teaching match that of the NSERC Chair - who is working toward a unified design culture in the Faculty of Engineering – there seemed to be good agreement. Mark's emphasis on active learning resonated with Barry's assertion that "learning is a difficult experience. It's facilitated by the professor, but the real work is done by the student" (22). In teaching design, this discomfort should be balanced by an environment "where it seems worthwhile to advance the effort to learn" (22). Gord's emphasis on learning by doing echoed Barry's comment that "you don't sit back and talk about this without doing it" (24). Peter's emphasis on bringing real-life examples and experiences into the curriculum, as well as the overall emphasis on providing industry perspectives and creating industry environments resonated with Barry's commitment to expose students to the big picture, to "take some of the more practical aspect of things back into the classroom" (5), because "if you're going to learn about design, you've got to be in the kind of environment that speaks to that" (23).

In reflecting on the comments of these four participants with respect to their approaches to teaching, it was evident that personal experiences were a key factor in defining teaching approaches. Examples of how and why they did certain things in the classroom were most often described in relation to a prior personal experience. For example, Gord cited the top-down teaching approach of a journeyman tradesperson when he was an apprentice as a key influence in how he developed an alternative approach to teaching his own apprentices later on. While all instructors agreed that personal experiences were key in shaping their teaching approaches, other influences included students' feedback; observing classroom processes; and seminars, workshops, and publications related to teaching. Mark noted that the culture that surrounds one also contributes to one's personal background and consequently to one's approach to teaching. He described his experience as a student and later a faculty member in departmental cultures in which creativity and initiative were valued and nurtured by departmental leaders and key faculty members:

> The response to a 'no' can be to either give up, which does not lead to creativity, or it can be to initiate an attempt to see how we can get around the 'no'. [Key faculty members] provided leadership to the department in taking the second response, and this leadership shaped my personal philosophy, too (paraphrase of off-tape discussion, 24).

While all participants could discuss their approaches to teaching at length, all found it more difficult to articulate a particular learning theory which guided their work, generally indicating their pedagogical understanding to be "more by accident than by education" (Barry, 29). These four participants indicated that they were aware that different learning theories exist, that they have been exposed to them to varying extents, but that they are not fluent in learning theory to the extent to recall respective theories or claim one particular theory as their own. The participants are also aware of a variety of resources at their disposal to learn about learning theories, and some indicated that it was "something on my list of things to do" (F4T2, 46).

In speaking about an appropriate learning theory for design without the context of a specific course, the NSERC Chair described various theories or theory components that he had found applicable to design education, including student-centred learning, apprenticeship models, problem-based learning (case studies), and team learning. In describing student-centred learning, Barry stated, "you let the student make the judgment. You provide the enthusiasm, the background, the resource to allow the student to explore the subject. You work at keeping the students focussed. The decision centre is the students. The resource centre is the professor" (39). Mark again referred to active learning as a tool that he has found helpful, describing it as "anything that engages students during the time we're together in class or the lab, or even the time when they're working on their assignments" (31), and describing learning as "an individual responsibility and an activity you take on yourself" (32).

In reflecting on learning theories, Gord indicated that while he wanted to be aware of different learning theories, he wasn't sure that he wanted to necessarily adopt one strategy but rather needed a set of strategies to teach a class that is very open-ended and informal. Apart from a classroom style that can potentially change over the course of the term, Mark also highlighted the need to accommodate both visual and auditory learners, while Peter highlighted the need to understand the learning styles of students along two dimensions: concrete – abstract and random - sequential. As a typical example, Mark stated "you're going to have students that have different learning styles, and you can't or you shouldn't use the same mode of delivery for the entire course. So you try to use a variety of instructional techniques" (30). In general, the participants' comments reflected a genuine awareness that teaching and learning are complex tasks, and that discipline knowledge alone is insufficient for good teaching.

After discussing the more general concepts of definitions of design, approaches to teaching, and learning theories, students and instructors were asked to reflect on the specific structure of the design trilogy courses, including course goals, course content, teaching strategies, learning experiences (assignments), and assessment & evaluation strategies. These results are summarized in the following sections. Industry cooperators were not asked to reflect on appropriate goals, content, teaching strategies, assignments, and assessment & evaluation strategies for design courses, since their involvement and interest in these areas was considered peripheral. For example, when asked to comment on an aspect of the course, Tim stated, "I'm not sure I can really answer that question accurately, so I don't think I'm going to try" (13).

Goals of the Design Trilogy Courses

The course goals articulated by students and instructors included both technical goals related to course content and design competencies, as well as goals related to student attitudes and general personal outcomes. The instructor's goals in the second-year course included developing a base understanding of the engineering profession and the role of an engineer; providing opportunities to develop oral presentation and written communication skills; and, having students engage in the design process to develop a design concept. Additionally, the instructor's goal was for the students to get to know one another within the cohort and between cohorts. Students recognized course goals as including exposure to the engineering profession, "getting an idea of what an engineer does" (FG2-1, 2), and exposure to project management. They also recognized that the instructor "wants us to do well" (FG2-1, 2). However, the second year cohort expressed uncertainty over the course goals and the goals of the trilogy in general: "maybe the goals will be illuminated by third or fourth year" (FG2-1, 2). Students were also asked to articulate their personal goals for the course, and these included to learn a skill better: "e.g. AutoCAD, a math skill, picking material better" (FG2-1, 2) and to design something: "to get some hands-on experience…to solve a problem" (FG2-1, 2). Students agreed that, besides the goal to learn a skill better, their goals were being met through the design projects.

The instructor's goals in the third-year course included introducing students to the theory of project planning; concepts of safety engineering and human factors engineering; having students engage in a group design experience in response to an industry problem; and, providing students with oral and written presentation opportunities. Additional instructor goals included developing independent thinking and students' abilities to apply concepts to their own design projects. Students recognized course goals as including developing project management skills, deriving a more developed design solution including a prototype if possible, communication skills, teamwork skills, time management skills, and consideration of safety in design. They further recognized course goals to include "developing our own way of thinking" (FG3-1, 2). Students' personal goals for the course included having an opportunity to experiment with design, to have fun, to find relevance to one's area of future professional interest, and to be challenged: "it's nice to tackle designs related to what you hope to go into after university" (FG3-1, 3). When asked to reflect back, students recognized the main goals of the second-year course to have been an introduction to design and developing a conceptual design idea, and developing communication skills, and a main goal of the trilogy to be "having the opportunity to repeat the process over three years" (FG3-1, 2). Students indicated that their learning goals were being met by repeating the same design activities every year, and through opportunities to 'learn by doing'. However, students noted the intuitively counter-culture nature of design education (relative to the dominant engineering curriculum) in which they perceived "no real standard to say if the goals have been met or not" (FG3-1, 2)

The instructor's goals in the fourth-year course included to have students move through a design challenge (design process), to further develop team function and time management skills, to engage students in self-reflection and self-analysis, and to have students reflect on their personal role within the profession, society, and humanity. In addition, the instructor stated, "I certainly hope they have a good experience" (F4T2, 52). Students recognized the first three goals of understanding the design process and developing team function and project management skills. They additionally perceived the course goals as including developing communication skills, expanding technical skills and technical knowledge, developing practical hands-on skills, and "giving us an idea of what we might be doing when we graduate" (FG4-1, 2). Students' personal goals for the course included good grades, practicing to use time wisely or "spread the work over the term" (FG4-1, 3), and to gain competence in the design process. More definitively than the other two classes, students affirmed that their learning goals were being met by the different activities in the current and previous trilogy courses. Personal goals were also being facilitated by Biosystems Engineering being a "very close-knit" department (FG4-1, 3).

Some transition appeared to be evident in the students' responses across the courses. Third and fourth year students appeared more readily able to articulate and adopt the course goals than second year students; the fourth year cohort indicated, "the prof's goals are also the students' goals" (FG4-1, 3). The personal goals of third and fourth year students were also future-oriented, as to the impact that their grades, their exposure to and competence in the design process may affect future professional opportunities.

Industry cooperators were also asked to reflect on their expectations of graduate engineers with respect to design. All cooperators mentioned that they needed and assumed graduate engineers to have a good general knowledge of fundamental engineering principles and theory. Cooperators echoed each other in stating that graduates should have a flexible attitude and a problem-solving mentality, in which they generate "innovative solutions tempered by a practicality" (Tim, 6) and where the limits of fabrication are known and respected. They should also possess competency with new technologies, and be fluent in project management tasks such as analysing the project, setting timelines, and projecting deliverables to fit clients' goals. Overall good people skills, fundamental curiosity, and self-directness were also highlighted as important qualities. In general, the expectations of the cooperators seemed to match the orientations that the instructors brought to the courses - in which design is seen as something much broader than a bounded technical skill set, but rather as a set of technical and non-technical competencies, personal characteristics, and "a mindset, the way one reacts to a problem" (Barry, 12).

Course Content, Teaching Strategies, & Learning Experiences

Once course goals had been articulated, course instructors and students were asked to discuss how course content, teaching strategies, and learning experiences (for example, assignments) facilitated the goals. Components of content and learning experiences for each course have been profiled earlier in this chapter (*The General Experience in the DT Courses*) and are not repeated here. In addition, all instructors relied on a combination of teaching methods in their respective course. The range of methods included lecturing, group discussions, guest speakers, case studies combined at times with role playing, peer teaching, and lab activities designed to teach concepts or develop skills. A transition was evident in that, of the three courses, the second year course relied most heavily on lecturing and the fourth year course relied least on lecturing, which also reflected the fourth-year instructor's priority to not "spend as much time going through things lock-step, but broaden the discussion out a bit" (F4T3, 74).

Instructors found it difficult to discuss each component separately, reflecting a general coherence between the content, teaching methods, and assignments in the courses. While not without exception, mapping each course's goals, content, teaching strategies, and assignments on a matrix also indicated overall congruence between the four areas. Further assessing the match between instructors' approaches to teaching and the administration of the courses (as demonstrated by content, teaching strategies, and assignments) yielded overall congruence as well. For example, in describing a set of lab assignments that introduced students to hands-on work with shop tools, reading drawings, and fabrication tolerances as they construct components to be assembled into an object, Gord indicated that students may ask,

> 'well, it says so many millimetres, plus or minus, does it matter if it's close?' and I'll say, 'Well, it's on the drawing, so it's your decision. How important is it to you?' And so it's left hanging a little bit, and there's a lot of informal learning that goes on, anecdotal stories, and they're also interacting with the technicians at the same time. And they enjoy it, too. So there's your discovery learning (59).

Mark similarly described how he planned for active learning in his class:

> I give them a scenario: 'design a helmet' or something like that. And they have to decide what relevant body dimensions are going to be needed in order to design this object. We're going on the assumption that there is no source of data for this, so they collect data from the population of students within the class and tabulate that, and then they also have to apply the principle of design they're going to use.

Are they designing based on the extreme within the population? Are they designing for the average? They have to make that decision (64-65).

Students' comments highlighted, however, that the coherence and congruence between goals, content, teaching strategies, and assignments were not always transparent to them. When asked to reflect on content areas that they considered useful in learning design, students readily cited concepts in project management and project planning, communication, safety engineering, ergonomics, economics, and the engineering profession. However, third and fourth year students were decidedly more positive than second year students about the contribution of these content areas to learning design, indicating that "even though some topics may seem trivial, they're important" (FG3-1, 3) and "most content is useful" (FG4-1, 3).

When asked to consider teaching strategies that facilitated learning design, students readily referred to their lab experiences: the Assembly Drawings assignment in second year, and constructing things in the shop. A third year student summarized by saying, "you learn by doing. It's pretty hard to be *taught* how to design" (FG3-1, 4). In the lower levels, guest speakers from industry and story-telling (instructors' stories and case studies) were identified as useful strategies. In the higher levels, group work time in class (design teams one-on-one with the instructor) were considered useful as well. The responses implied the desire for directedness in teaching at the lower levels, transitioning to more guidance in the higher levels.

When asked to consider assignments that facilitated learning design, students again readily referred to laboratory experiences, as well as the brainstorming session, speaking assignments, and teamwork. Fourth-year students also referred back to specific tasks in previous years (GANTT charts, timelines) that they considered more worthwhile in retrospect. These students also highlighted the value of technicians' feedback on their designs more than the other two classes. Again, students emphasized the importance of 'doing' in learning design: "maybe the best way to teach design is by experience and example" (FG2-1, A, B, D).

A key area where students appeared to perceive a lack of congruence in the DT courses related to lecture content and lecturing as a strategy. In discussing content, teaching strategies, and assignments in learning design, all three classes spent a considerable amount of time debating the role, importance, and success of lecture content and of lecturing in learning design. Students acknowledged that some lecturing is needed "because you can't learn everything on your own" (FG3-1, 3). Students also seemed eager to give instructors the benefit of the doubt and generally held instructors in high regard. Nonetheless, students' comments revealed a sense of dissatisfaction with lecturing as a teaching method, the content of lectures, and the relationship of lectures to the design projects.

While each course relied to a lesser or greater extent on lecturing for content transmission, instructors were certainly aware of the pitfalls of straight lectures and demonstrated efforts to make lecturing interactive. Peter stated, "I try to ask questions as we go through, ask for their experiences or ask for their opinions when we get to certain points" and "I'll bring in some of my real-world experiences…which I hope enhances the value of the information" (52-53). Mark also indicated,

> Rather than me simply writing down or dictating a list of <u>my</u> own thoughts on a particular topic, I try to use brainstorming and classroom discussion to get the

> students involved, and hopefully take pride in the fact that they're generating some of the key points that ultimately we'll continue to talk about in class (31).

Instructors were also able to reflect on why they had chosen certain course content used in a lecture/discussion mode. For example, the second year course, taught in the cohort's first term in the Biosystems department, deliberately introduces Biosystems Engineering and its history, and profiles the engineering profession generally (its regulation and code of ethics). In the third year course, the instructor consciously deliberates on appropriate content to transmit concepts in lectures. In deciding to include human factors engineering into the third year course, the instructor cited "a logical fit that a biosystems engineer should have some introduction to human factors engineering" (37). In covering safety engineering concepts in the same course, the instructor chose content related to *agricultural* hazards specifically, because

> agriculture still tends to be either the first or second most dangerous occupation in North America, and if we can use the vast number of hazards that are associated with agriculture to illustrate the importance…and how you could avoid those hazards, you should be able to apply that to any industry (F3T2, 45).

Despite clear linkages across lecture components and other course experiences on the part of instructors, student focus group participants in all three cohorts expressed the perception that lecturing and lecture content was often unrelated to other parts of the course, and to their design project in particular: "There seem to be two separate entities, the class and the design project" (FG2-1, C), "it seems like the course has two sections that operate independently: lecture and design project" (FG3-1, 5), and "sometimes lectures seem like a separate course" (FG4-1, 3). A key concern related to a perceived lack of *context* – preferably one of the design projects – for the lectures:

> The project should not be a chunk of the design course. It should *be* the design course – that is the vehicle to learn all the aspects of design. Then the lecture material is grounded in the project. Material could be presented and applied to a project, and you could be evaluated on how your team has applied the principles to your own design project (FG3-2, A).

Another key concern across the three classes was a perceived lack of *relevance* of the lecture material: "some lecture content is good material, just not necessarily part of the design process, like farm safety. It seems they don't know where to put the content" (FG4-1, 3). The concern had several facets. One concern was that lecture material was not relevant to the design projects: "lecture content takes time away from the project and is not relevant to the individual project" (FG3-1, 3). A second concern was that the lecture material was not relevant to the students' personal interests and their perceptions of what Biosystems Engineering encompasses. Students in several classes discussed their personal interests in biomedical engineering, and their perception that "they've changed the department name [from Agricultural Engineering to Biosystems Engineering] but the focus is still very much on agriculture" (FG3-2, A) to the neglect of other biosystems. Again, some students readily acknowledged where their instructor had recognized these broader interests and attempted to incorporate them into the course.

Instructors demonstrated sensitivity to what topics were being covered in the other courses, in terms of wanting to ensure that the progression of content throughout the trilogy is coherent. While at times implying they may not communicate with each other (as instructors) as much as they would like to, a typical comment was also that "I've got a bit of a concern that we're duplicating material…, and I need to review with the other two instructors to see what we all are covering" (F4T3, 73). When asked about how he chose specific content for his course, another instructor indicated that he was aware of what was being covered in the other two courses, and so he didn't feel he needed to cover those topics again.

Students perceived some content duplication and generally were willing to give instructors the benefit of the doubt, in terms of the instructor having an unstated reason to duplicate material from one course to the other. However, third and fourth year students also commented, "a lot of the lectures are basics we've already learned earlier in the program. We just need reminders now" (FG4-1, 3)

The fourth year course presented itself slightly differently, in that the instructor repeatedly referred to a deliberate attempt to make the content open-ended and responsive to "anything that happens to come up in the course" (F4T2, 69). As an example, the instructor may spend time focussing on team function and conflict mediation, if it became apparent at some point that a design team was struggling with these issues. This course also appeared, more than the other two courses, to rely on classroom discussion, and the instructor acknowledged,

> If you're an individual who feels that it is important to keep everyone around the table engaged in the discussion, then you use phrases like, 'well, what do you think?'. There are some individuals who will see that as an opportunity to jump at that, because the perception is often that you aren't as competent, or that you've got a weak side (F4T1, 15-16).

The fourth year students perceived the fluidity in course content, and while they generally showed positive attitudes to the course, the instructor, and the trilogy, they did comment that "all the lectures are very loose – no textbook to follow, no class outline. Sometimes you wonder, 'do they know what they want to teach you?'" (FG4-1, 3). This perception was not limited to this class, though. It also extended to the second year class, which has – by all appearances – a structured pedagogy. One student commented, "they're trying to get at something, but no-one seems to be sure of what it is" (FG2-1, 3). The apparent sense of disconnect between instructors' intentions and students' perceptions relative to course content, teaching strategies, and learning experiences raised several implications for teaching, which are discussed in Chapter 5.

In addition to being asked to reflect on the courses as delineated by content, teaching methods, and assignments, students were also presented with a list of desired components for design courses as derived from the literature. They were asked to reflect on the extent to which each component, on a scale of one to 10, was *a part of their experience* in the trilogy courses. These findings are summarized below. It should be noted that the students' numerical ratings do not reflect students' perceptions of the *importance* of the components, nor their perceptions of how well the components were *articulated* in the courses.

1. Design projects. Students' ratings, varying from 8 in second year to 8-10 in fourth year, indicated that the design projects were a significant part of their course experience. Students commented, "it's the main component" (FG4-2, 1), and the majority of the students cited the projects as important vehicles in learning design: "they are preparation for the real world. You need practice in doing something; without that, you don't really learn. The projects develop skills" (FG3-2, 1). In higher level courses, many students also felt that other assignments were too time-consuming, "taking time away from the design project" (FG4-1, 4). In a post-interview conversation, one instructor acknowledged this risk, indicating the dilemma of wanting to include assignments that one considers useful, while simultaneously respecting the demands of the design project on the students.

2. Collaborative teamwork. Students' ratings of the emphasis of collaborative teamwork in the course increased from 6-9 in second year to 8-9 in fourth year. Many students cited the opportunity to work in teams as positive aspects of the course: "one of the more beneficial aspects has been working as a team" (FG3-1, 4).

3. Industry collaboration. Students' ratings of the emphasis of industry collaboration in the courses increased from 3 in second year, 2-5 in third year, to 4-6 in fourth year. While there was a general sentiment that collaboration with industry partners was "not a big part" (FG3-2, 1) of their experience, students also agreed that the extent that they perceived collaboration with industry was project dependent. As indicated earlier, students recognized an industry *perspective* in the courses, stemming from instructors' experiences in industry and working on design problems provided by industry.

4. Interdisciplinary focus. Students were asked to consider to what extent their course took them to subjects outside of biosystems engineering to other engineering disciplines, and to subjects outside of engineering entirely. Students were less unified in their ratings on this component. Projects were generally rated high (above seven), with comments that the "it encompasses everything, from heat transfer to marketing" (FG2-2,

1) and "biosystems engineering seems to be almost by definition inter-disciplinary" (FG3-2, 1). Classroom (lecture) content was generally rated low (below three) in this component.

5. Oral and written communication. All three cohorts recognized a deliberate and sustained effort to emphasize communication skills in all three classes. This component was rated 8-10 by all three classes. One student commented, "everything [in the course] is part of your [final design project] report and presentation; it all comes down to that" (FG4-2, 1).

6. Lectures. Consistent with information obtained from interviews with the instructors and discussed earlier, the students' ratings indicated that lectures were a large part of their course experience in second year (rated 8-9) and became a lesser part of their experience as they progressed through the trilogy (rated 7 in third year and 2 in fourth year).

7. Leadership experiences. While developing leadership skills did not emerge as an explicit course goal for either instructors nor students, the literature highlights this component as important in design education. Students' ratings of the emphasis of leadership development in the courses increased from 3-4 in second year to 5-7 in fourth year. Second year students commented, "the group takes precedence over individual leadership opportunities" (FG2-2, 1), while by fourth year, students recognized that "within each team, a de facto leader emerges for various phases" (FG4-2, 1).

The three student cohorts generally agreed that while all seven components taken from literature were important in learning design, lectures generally were given a lower importance than the other six components. Second year students commented that the lecture content related to the history and organization of the engineering profession was not related to design, while fourth year students reflected, "lectures are less important as you get into higher levels of design, whereas in the first and second courses of the trilogy, you can use the additional guidance" (FG4-2, A).

Assessment & Evaluation

In addition to course goals, content, teaching strategies, and learning experiences, instructors and students were asked to discuss assessment and evaluation strategies that were used in the courses and which they considered to be appropriate for design education. Student assessment was conceptualized as opportunities for students to receive non-graded feedback on their performance from the instructor and from their peers, formally or informally. Student evaluation was conceptualized as opportunities for students to receive graded feedback on their performance from the instructor and from their peers, which would cumulatively comprise their course grade.

When asked to describe if and how assessment was planned into the courses, instructors readily referred to the significant amount (generally 80 minutes per week) of unstructured class time, in which the instructor would circulate among student design teams. In addition, the instructors all committed to providing feedback to design teams on a draft of their final design report, and to debriefing the final design presentations with individual design teams. Planned assessment opportunities from peers included the joint brainstorming session and the 'contracting out' assignment. Receiving the feedback of departmental technicians on their design projects was another assessment opportunity for students. In addition, the second year course emphasized practicing oral communication skills via regular, short, in-class presentations. These classes also became opportunities for peer and instructor assessment. The third year class was required to complete a project portfolio, described by the instructor as "essentially reflective" (F3T3, 66). Students likewise recognized and appreciated many of above-mentioned assessment opportunities.

Two instructors also reflected on their own teaching styles as having assessment elements, where they structure classes to empower students to make their own decisions. Gord describes the open class times as follows:

> Typically I wander in, pull up a chair and just sit there and listen for a while. Sometimes I'll jump in, depends on what the issue is. Other times I'll get a sense where people will be talking about something as if it's a question. They'll say, 'well, I think we should do this', and then they'll kind of look [at me]. And that's when I'll take that body language as a cue to say, 'well, okay, but what about this', or move it to the next stage and facilitate the discussion onward. I think it's important to give them permission to make decisions. They can do that" (83-84).

Other instructors commented on the difficulty in handling this open class time as an assessment opportunity: "on the one hand I try to stay back. The students need time to work, and if I'm constantly looking over their shoulder, they don't necessarily feel comfortable just working. So it's a bit of a balance" (Mark, 71). Peter echoed this concern for striking the right balance, asking, "how much do you hold their hand through this whole thing?" (72).

This dynamic tension is also felt by students. One student commented, "we could have used more guidance earlier on. The prof had experience and knowledge we could have used, then we could have presented a more realistic design to the technicians. More specific feedback during the process would have been helpful" (FG3-2, A). Several students expressed a different concern: "the instructor is very positive. We could use more critique in the feedback" (FG4-2, 3). A shared sentiment between cohorts appeared to be that the quantity and quality of assessment appeared to be related to the instructor's level of expertise in the area of the student's specific design project.

When asked for suggestions relative to assessment in the courses, all cohorts spontaneously suggested more structured feedback at defined intervals, to ward off procrastination and for students to show progress and receive regular feedback which could be applied to their project. The fourth year class identified the deadline to hand in a draft of the final design report as a "defined assessment point" (FG4-2, 4) and suggested more such defined assessment points earlier in the term. The other two classes suggested a bi-weekly interval for feedback or regular check-ins.

In discussing student evaluation in the courses, instructors were asked to consider both *what* they evaluated and *how* they evaluated student learning. In terms of *what* was evaluated in each course, there appeared to be general congruence with the stated course goals and the course content and learning experiences. In all courses, students were evaluated on their final design project report (weighting ranged from 25% in second year to 50% in fourth year) and on course content through written tests or exams (weighting ranged from 50% in second year to 10% in fourth year). The remainder of a student's course grade was derived from evaluation of some combination of public speaking assignments, design assignments, group contribution, a project portfolio, and peer evaluation.

In delineating *how* students were evaluated, all course instructors identified four evaluation strategies used. These four strategies were instructor evaluation of an individual's performance (e.g. written tests, mid-term, and final exams); peer evaluation of an individual's performance (e.g. all classes – 'contracting out' assignment); peer evaluation of group performance (e.g. all classes – individuals rate fellow group members' contribution to the design project and this mark becomes a normalizing factor to each individual's respective project grade); and instructor evaluation of group performance (e.g. all classes – 'contracting out' assignment).

The evaluation schemes were also discussed with the student cohorts, and students' dominant concerns related to the use of written tests or exams, the relative weight of tests and exams relative to the design project, and the criteria used to mark the design project. Written tests and exams weigh most heavily in the second and third year course, and these instructors both indicated that they try to design tests to "get students to give their opinion, rather than just regurgitate information" (F2T3, 70) and to reflect the higher levels of cognitive learning: analysis, synthesis, and evaluation. Nonetheless, students still perceived that written tests and exams were not useful evaluation tools in a design course: "you can't test design skills on a midterm written by yourself in a desk" (FG2-2, E). Other students agreed that the trilogy courses are primarily about a design project and communication skills, commenting that "answering questions about [specific design concepts] on a written exam is not useful. You should be evaluated on whether your personal design project has taken these principles into account" (FG3-2, A). Again, students demonstrated willingness to see both sides, in that all cohorts acknowledged that written tests or exams likely need to be used, "or else the lectures have no point" (FG2-2, B)

A further student concern related to the weight of tests and exams relative to the design project in students' final mark. In the second and third year course, the contribution of the design project components to the final course grade was relatively equal to (third year) or less than (second year) the contribution of written tests, exams, and other course assignments. Students perceived that in these cases, the project was weighted too low relative to the time commitment it required and its predominance in the courses. Students expressed both disappointment that the bulk of their course work was weighted - in their opinion - too low, and suggested that the evaluation scheme held "no incentive to engage in the project" (FG3-2, B, G).

The final dominant student concern regarding evaluation related to the criteria used to mark the design project. When asked to outline the evaluation criteria for the final design report, instructors were able to outline several criteria, and one instructor was able to provide a detailed marking rubric. The majority of criteria related to technical communication issues: grammar & spelling, clarity of writing, logical format, and evidence of the design process (problem statement, description of solution with accompanying figures and analysis, etc.). In general, the design projects were evaluated on the extent to which they demonstrated that students had engaged in the *design process*. When asked to what extent, if any, the projects were evaluated for the technical feasibility and credibility of the final design solution or outcome – the *design product* – all instructors indicated that it was not to a great extent. They supported this decision with reasons, including congruence with the courses' goal for students to go through a design *process*, and students should not be penalized if their project was of too large a scope or too technically complex for them to come up with a workable design in the 13-week term. Instructors echoed each other in saying, "I'm less concerned about the product as opposed to the process. It's a case of how they handled the steps along the way" (F4T2, 45), and "in reality, the projects don't necessarily mesh with my technical expertise, so I'm not the best person to judge whether it's going to work or not" (F3T3, 70).

The NSERC Chair's comments also reflected the view that evaluation of the design process should be primary, and evaluation of the design product secondary: "allowing students to go wherever it takes them, and not judging the work by the end product, but by the process of [getting to] the end product" (Barry, 38). The justification for this view of design education points to a broader vision for design education within the entire faculty. Barry suggested that currently, individual engineering departments approach design from an 'end product' focus and a 'tool' focus – how to use a particular piece of analysis. The result is that "the circuit design people and the power systems people see the design process as entirely different in their two different worlds" (44). Barry firmly believes in design as a mindset or a way of approaching problems that transcends disciplines, and this subsequently leads to a *design process* orientation to education.

Nonetheless, third and fourth year students, in particular, expressed frustration that their design projects are not evaluated to any great extent on technical feasibility or workability: "the grades just reflect the design process, but not the feasibility of the design itself" (FG4-1, 5). Sentiments inherent in student responses were frustration at a lack of completion of the design process and the learning process, an unfulfilled curiosity and desire for feedback on their work, and an unfulfilled sense of pride in their result.

In addition to desiring some evaluation of their end product of design, students also considered it appropriate to be evaluated on team function, communication skills, and how well the design project integrated design concepts presented in class. When asked to consider which evaluation strategies they found useful and appropriate for design education, students highlighted peer evaluation, interim progress reports, one-on-one debriefings with the instructor, and feedback from their industry cooperators.

Given these student views, the industry cooperators were asked whether they would perceive a benefit from being involved in determining the student's course grade, either to themselves personally and/or to the students. By and large, cooperators were either ambivalent or cool to the suggestion of being involved in student evaluation. Several cooperators indicated that if this was required of them, they would like to know that at the point applying to be involved as a cooperator. Others expressed concern that students would be worse off if evaluation criteria were not clearly spelled out for the cooperators, and students ended up being evaluated on differing expectations between cooperators: "we would create an uneven playing field for the different groups" (Tim, 12). At best, cooperators indicated that they were not seeking the opportunity to be involved in formal evaluation, or that they did not perceive that as their role: "it's not our job to educate the students" (Cameron, 11). In explicitly differentiating between student evaluation versus student assessment, Randall stated that it would be worthwhile for industry cooperators to provide constructive feedback: "what the students could have done better, or things to think about for the future, …versus… scoring them" (18).

Cognizant of most industry cooperators views on providing student evaluation, the NSERC Chair proposed that industry input into student evaluation can come via Engineers-in-Residence, an initiative of the NSERC Design Chair program in which industry engineers are brought into the university community as a learning resource to students. These individuals can transcend classes and student teams and, together with other faculty and technicians, can provide technical assessment and evaluation in their areas of expertise.

The preceding discussion highlights a general coherence between the instructors' course goals and their assessment and evaluation strategies, also to the extent that strategies resonate with the NSERC Chair's vision for design education. The findings also highlight points of frustration for students, where the coherence – though it may exist – is not apparent to the students. The findings on course goals, content, teaching methods, learning experiences, and assessment and evaluation strategies encompassed the dominant concerns of course planning. An additional pedagogical consideration in any learning environment is the role of the instructor, which is presented in the following section.

Role of the Instructor

The NSERC Chair, the three course instructors, and the student participants were asked to describe the appropriate role of a design instructor, and to attempt to define appropriate 'teaching' in a design course. Students all agreed that 'teaching' and the role of the instructor in the trilogy courses were markedly different from 'teaching' in other courses, and most of the differences that the students highlighted were positive. Senior students highlighted the design project and hands-on experience as a factor that made teaching different. Both third and fourth year students highlighted the small class size and interaction, collegiality, and informality of a small department that permeated the courses: "it's our department's course; that makes a big difference" (FG4-1, 4). These students also highlighted the predominance of industry perspectives as unique to the course, including learning things about industry, being given an actual design problem from industry, making contacts in industry with potential spin-off opportunities: "it's more like engineering in the real world" (FG3-1, D).

However, some students indicated that the extent to which 'teaching' in the DT differed from other courses varies from instructor to instructor and especially from class to class: "when it's a standard lecture class, then it's not so different" (FG4-1, 4). All participants in the second year class also perceived teaching to be different, but their comments revealed a frustration and sense of unease with the intuitive differences between design and the analysis courses that dominate the curriculum. These students referred to a lack of structure and commented, "design is not quantifiable. There is no theory of design, no formulas, so you can't teach it like other classes" (FG2-1, B, D), and "it seems like someone's opinion. It lacks a theory base and seems unresearched" (FG2-1, C).

Presuming that to make 'teaching' different – as students had recognized – would require a non-traditional role for a design instructor, the NSERC Chair and the course instructors were asked to reflect on the appropriate role or profile of a design instructor. These participants repeatedly used the terms 'facilitator' and 'resource', which includes roles of helping students define boundaries, validating the work they've done, and empowering student to move forward. They referred to the need to be seen as a real person, with "courage to empower the students, as compared to seeking the control" (Barry, 37), to be open to challenge from the students, and being able to explain 'why'. Barry and Gord highlighted that the role is distinctly not that of 'sage on the stage', and in such a role, the instructor is constantly challenged to stay on top of the subject matter and acknowledge that students' knowledge and experiences may surpass his or her own. Peter commented, "[teaching] keeps me more on top of things I should be doing and learning myself" (22), while Gord stated, "as a facilitator, you're opening yourself up and realizing, 'these people know a heck of a lot more than I do'" (51).

Students were also asked to describe their perception of the appropriate role of a design instructor. To assist them, two potential instructor roles – Sage on the Stage, Guide on the Side – were characterized. Students agreed that between the two options, Guide on the Side was the appropriate role, and additionally used the terms 'consultant' and 'mentor'. When asked to define desirable characteristics of a design instructor, common responses across cohorts included an industry perspective, industry experience, and design experience. Additionally, students felt a design instructor should be able to resource students, give specific content and expertise when needed, and should be enthusiastic, approachable, available, and organized. One cohort also mentioned that a design instructor should bring mediation skills and insight into group function to the learning process.

Students were aware that carrying out the role of guide, mentor, and consultant can be a tricky balance, given that students' individual learning styles and personalities may prejudice them to a certain instructional role, and that the role of Guide on the Side can at times feels "too hands-off" (FG3-2, A). Students also acknowledged that the role of guide, mentor, and consultant "is probably more intensive for the prof because it is less structured" (FG4-2, 2).

Learning Outcomes

In addition to characterizing the role of the instructor in the DT, all participants were asked to consider the student learning outcomes they identified as students progressed through a course, through the trilogy, and/or through a design project.

Students' responses indicated a high level of agreement among participants and between cohorts. Students agreed that they had learned "a better feel for what engineering in the real world is like" (FG3-2, D) and team skills. Third and fourth year students indicated learning outcomes to include communication skills and project management skills. In third and fourth year, students also mentioned outcomes in technical knowledge in their project area and comfort with the design process. Fourth year students agreed that learning outcomes had improved over their three years in the trilogy: "every year you do it, you build on the year before" and "you learn from mistakes, sometimes two or three times over" (FG4-2, 3).

Instructors identified many of the same outcomes in students: working in teams, an overall progression in communication skills over the three courses, and increasing comfort with and competence in the design process. One instructor commented, "there certainly is a *huge* progression [in communication skills] from the second year to the fourth year students. I don't think that can be attributed to any one class. I think it can be attributed to the whole process" (F3T3, 76). The second year instructor identified learning to deal with the client, an enhanced understanding of the engineering profession, and bonding within the cohort as positive outcomes: "you've got real bonding going on in the group,…they've progressed very well with that" (F2T3, 83). The third year instructor identified in students an increased willingness to participate in alternative instructional approaches, and an internalization of considering safety and human factors in design by the end of the fourth year course. The fourth year instructor identified students' relational maturity, abilities to do research, comfort with limited information, and abilities in higher levels of analysis and modelling, commenting "it reminds you that you can never let the grass grow under your feet either" (F4T3, 86). The learning outcomes appeared consistent with what one would hope for in cohorts that come together as strangers in the second year and progress through the DT together for three years, in small class sizes.

When asked to reflect on their personal learnings outside of what they had *expected* to learn in the courses, students identified an internalized feeling that others are relying on you and "you don't want to let the group down" (FG2-2, 2), learning to work with diverse people and respect "the nuances of each person" (FG4-2, 2), and a self-awareness of one's personal working style. Second year students also identified in themselves an enhanced perspective of engineering: "how technical courses are all tool or pieces of a bigger concept" (FG2-2, 2).

Consistent with the students' own perceptions, the NSERC Chair also characterized the major learning outcomes in students as a team orientation and a broadened perspective. He commented, "it was always 'my thesis', 'my project', and [now] there's a lot more 'we'" (Barry, 73), and "they're much more comfortable with the fact that the answer they get depends on the question they ask, and they're much more inclined to ponder the question to say, 'is this what you're really after?...They're not as willing to accept constraint'" (Barry, 73; 75).

The industry cooperators could not be expected to comment on detailed student learning outcomes, but were asked to comment indirectly by evaluating the strengths of the design projects. Cooperators generally expressed that students did well: "on a scale of one to five, with one being the best, I'd give them a two" (Tim, 2), and "the students did a very good job" (Randall, 19). When asked to identify particular strengths of the projects, cooperators commented that students had defined the scope well, done a lot of research, evaluated a number of different options, and derived a design concept that in some cases was potentially feasible and could be moved forward. Cooperators also agreed that students' presentation skills were good: "they were all a good amount and there was a good energy about them" (Cameron, 14). One cooperator who had provided two projects to the trilogy commented that he noticed that the students in the higher level course had more quickly been able to focus the problem, ask detailed questions about it, and derive a design solution than the students in the lower level course. A cooperator whose project had been assigned to a fourth-year design team also noted strong team skills, professionalism in communication, and the high calibre of the final written report. Most cooperators agreed that the students had developed design skills: "it teaches them to learn and how to problem-solve" (Cameron, 12).

The previous sections of this chapter have dealt with the experience of the DT and the participants' experiences of teaching and learning in the courses, including teaching approaches, goals, content, teaching methods, learning experiences, assessment &

evaluation, instructional roles, and learning outcomes. The following sections focus on administrative aspects of the courses, including collaboration between participants, assessment & evaluation of the DT structure, and considerations for transferring the DT model to other engineering departments.

Structure of the Design Trilogy

Currently, Mark is the only full-time academic faculty member of the three instructors as well as one of the original faculty members involved in conceptualizing the DT model. Thus he states that "it seemed logical that I take on the role of course coordinator" (9). In the words of another instructor, "Mark is really the glue that holds this all together" (Peter, 84). In this informal coordinator role, Mark ensures that a sufficient number of design projects of a sufficient nature are available before the term begins. For the 2002-2003 academic year, design project recruitment was handed over to a centralized unit in the Faculty of Engineering (IDEA) which recruited projects for all engineering departments with design courses, including Biosystems. Upon recruitment and acceptance, IDEA and Mark met to decide which projects were most appropriate for the Biosystems DT courses. Mark, in consultation with the other two DT instructors, then assigns the projects to the various years of the trilogy, based on the nature of the projects. A second part of his informal coordination role includes attending to logistical administrative details, such as booking a room for end-of-term final presentations. A third component of the role includes evaluating what happened in the DT in the past year and trying to determine whether changes should be made. When asked to elaborate on how this evaluation was done, Mark indicated that it wasn't "a formal mechanism" (59), but rather an alertness to difficulties and conflicts that arise throughout the term, and initiating discussions with the other instructors prior to the next offering of the courses. In addition, Mark commented that new teaching ideas that he gets from publications, seminars, and the like also become part of the evaluative process year-to-year.

Faculty Collaboration

All three instructors were asked to discuss the extent and nature of their collaboration with one another. A general sense emerged that the overall amount of collaboration was not high due to a combination of factors, including two instructors' commitments that took them off-campus and a generally high workload for all involved. Gord cautioned, though, that while "more time would be good, I don't know that you'd want to force it to happen if it's not going to happen organically" (87). Instructors referred primarily to three situations in which collaboration happens: collaboration around design project selection and design team assignment, informal opportunistic 'in-the-hall' interaction, and year-end reviews and debriefings.

Mark indicated that after projects come to the department from the IDEA program, the three instructors collaborated on assigning individual projects to individual courses. Early in the term, the instructors also sat down together to assign student teams, based on the one-page proposals that students fill out, indicating their preferences. Instructors also met to discuss evaluation strategies, particularly for assignments that were common to all three courses: "to make sure we're evaluating this in a fairly consistent way" (Peter, 88). Instructors also reflected that chance meetings in the hall or phone conversations about unrelated issues often turned into times of opportunistic collaboration: "we tend to chat about how things are going in the course" (Mark, 78).

Finally, Gord commented, “we always create spaces to do reviews of the year, what we’ve learned, and what to do for the next year” (87), emphasizing that changes need to have solid rationale.

Student Collaboration

Besides faculty collaboration, instructors were also asked to discuss ways in which student collaboration (across the cohorts) was built into the DT structure. Findings revealed dominant points of collaboration to be common learning experiences which brought all three cohorts together, including the fun design exercise / mixer at the beginning of the year, joint brainstorming sessions, ‘contracting out’ assignment, joint lectures with guest speakers, preliminary presentations to the other cohorts, and final public presentations. One instructor also noted that the three classes use the same physical lab space and have a chance to observe each other there.

Although the courses had the above-mentioned experiences for planned student collaboration, students’ perceptions of the extent of collaboration between the three courses varied greatly. Individual participants indicated that they felt some degree of continuity in the courses: “I’m building on last years’ knowledge, but having new experiences” (FG3-2, B), and “there is a link in the courses in the projects” (FG4-2, E). The general sense, though, emerged that although students perceived the courses to have some similarities, they did not perceive an overall feeling of continuity, collaboration, or ‘trilogy’ in the courses: “the three courses are similar in terms of style and assignments, but not much more” (FG4-2, 4).

Students’ suggestions on improving the connections across courses and enhancing the feeling of ‘trilogy’ related to receiving information to give them confidence that the course instructors were collaborating and that the courses had indeed been conceptualized as a trilogy. Students recommended revisiting course content and "making it flow" (FG4-2, F) as a trilogy, avoiding duplication of content and overlapping of goals. Students were also in favour of receiving a syllabus for the Design Trilogy overall, to outline the vision of the trilogy and sets milestones that students should be achieving in each course: "what is the final big picture" (FG4-2, C).

Gord reflected that initial goals of the DT included more synergy, but that the structure of the academic environment works against it. For example, an original hope of the DT model was to take one project in second year and have the design team carry it through as they progressed through the three courses, so that students add more detail to their design in each subsequent year. All student cohorts also suggested using the design projects to create a feeling of trilogy: each design team following the same project through all three years of the trilogy, or breaking one project into different components for all teams in all three cohorts to work on in a given year. Instructors and students alike recognized that not many industry cooperators have three years to wait for the final design solution: "whether industry could provide good projects for a three-year timeline is questionable" (FG4-2, A), and thus the projects would run the risk of becoming an academic exercise only. Previously-noted comments from students also indicated that part of the enjoyment and relevance of the courses is because they transcend an academic exercise and link into real-life industry. Students further acknowledged that working in design teams newly created each year enhanced team skills, and the exposure to three different projects over the course of the trilogy enhanced learning. Second year students suggested enhancing collaboration and synergy by using third and four year students to give them feedback on their projects throughout the term.

The comments of instructors and students alike communicated a sense of frustration that the level of synergy or 'trilogy' feeling of the courses, as originally intended, had not yet been achieved. At this point in the evolution of the DT, a main obstacle appears to be that the most readily-suggested changes to enhance synergy have serious logistical limitations.

Strengths & Challenges

Instructors recognized that courses continually need to evolve in response to changing local and global realities: "what may have been a strength of the department ten years ago may no longer be even relevant" (Mark, 2). Instructors were also able to articulate some of their goals, plans, or suggestions for their particular course and for the trilogy overall. Two instructors expressed concern that the courses – with the combination of the major design project plus other assignments and tests – may be taxing students' time:

> I sense it from the students, that we've got all of these little activities that they're doing throughout the term, which [the instructors] see the value in, but they all take time away from the design project. The project *should* be the focal point (Mark, 79).

This concern, coupled with a desire to be vigilant regarding potential boredom among students at having to repeat the design process in three consecutive years leaves the instructors open to potentially major organizational shifts in coming years. While no such shifts have been finalized at time of writing, the scale of such shifts may include removing the design project requirement from one of the courses and redistributing student labour among the cohorts.

More immediate plans for the courses included reviewing content to avoid duplication and ensure continual challenge, to continue to seek guest speakers, to develop activities and content with an overall purpose in mind, and to be vigilant in vetting projects to ensure that their nature and scope is not too ill-defined for students.

Students were given an opportunity to express both their positive perceptions of the courses, as well as their frustrations and challenges in learning design in the DT. Students had many positive things to say about the courses, many of which were referred to in an earlier section (*The General Experience of the DT Research Participants*). To re-cap, positive and enjoyable aspects of the courses included the design projects, working as teams, contact to industry (through instructors and industry cooperators), exposure to real-life problems, a relaxed, informal atmosphere (including a small class, collegial relationships with instructors, and high levels of interaction), practical shop experiences, and the ability to develop personal interest and personal responsibility.

However, as detailed in an earlier section (*Teaching & Learning Engineering Design*), all participants in all three cohorts felt frustrated at a sense of disconnect between the lectures and the design project: "sometimes they seem like two separate courses" (FG3-1, 5), as well as a perception that lecture material lacked context and relevance. Also discussed earlier, students expressed frustration that design projects were not graded for the feasibility or technical credibility of the design itself.

Second year students expressed frustration at the perceived lack of a theory base and quantifiable process for design. Third and fourth year students did not mention this aspect, implying a transition in comfort with this ambiguity as students progressed through the DT. Students expressed further frustrations related to their experience in the DT and with the design project specifically. Some students felt that instructors were good at helping groups whose projects matched their own areas of expertise, and that other groups tended to suffer. When asking for guidance and assistance, some students' perceptions of instructors' roles of Guide of the Side were that they were not given adequate assistance or feedback at the appropriate times. A major frustration for higher level students was their perception that the design process was truncated prior to completion, due to the time constraints of a 13-week course: "I feel that the process was cut off" (FG3-1, 5), and "we would like to see and gain insights from the testing process, … and take projects to the manufacturing stage" (FG4-1, 4).

Students demonstrated their overall positive attitudes in that their expressions of frustration were most often accompanied by ideas and suggestions to address the frustrations in the learning process. Third and fourth year students spent a fair amount of time discussing options to modify the course structure to address the feeling that the design process was not carried through to completion and the desire to carry projects to the testing / manufacturing stage. Suggestions included making the course a 6-credit course over two terms, having one project that groups follow through their three years in the trilogy, or fourth-year students receiving projects where front-end work (conceptual design and research) had been completed. Instructors were aware that the design process is often cut off for students prior to full prototyping and testing, and that this can be a major frustration. As discussed earlier, students and instructors were both aware of the limitations of choosing one project to carry over three years. Instructors also highlighted their personal frustration that time in the course and the physical facility constraints of the university limited students' ability to reach a prototyping and testing stage in their projects. This constraint appears to be linked to instructors' hesitancy to place a lot of emphasis (grades) on the technical feasibility of the final design product, and Barry commented, "there's no question at all that's a weakness in the process" (72).

Additional suggestions from students for an improved learning experience related to creating context and relevance for lecture material by grounding lecture concepts in a design project, as discussed earlier. Students also indicated interest in an increased use of case studies in teaching, more guest speakers from industry, and interaction with business students. One student commented, "class time should be used to do things you cannot do on your own, for which you need your classmates' presence" (FG3-2, A). Additionally, second year students appeared to struggle with the diverse nature of their course content: "it seems like a catch-all course" (FG2-2, 4) and suggested it needed "a focus" (FG2-2, 4).

What should not be missed, though, was students' overall enthusiasm and positive energy toward the DT. Typical sentiments included "it's a good course, because it's different from all the other courses" (FG2-2, D, E), "the workload is high, but because you get to pick what you work on according to personal interest, it makes it enjoyable" (FG4-1, 4), and "overall, it's very positive. And like any other new initiative, there are kinks to work out" (FG4-2, 4). The NSERC Chair echoed that although teaching in the DT often feels like a trial-and-error endeavour, something is going right: "industry people who hire biosystems engineers and other kinds of engineers come back to the department and say, 'those students from biosystems, they can do this, this, and this, but the other students have trouble with that'" (Barry, 45).

Perceptions of Industry Cooperators

Industry cooperators were also given the opportunity to discuss positive and negative perceptions of the projects themselves, as well as their suggestions for the administration of their involvement to enhance their experience. Industry cooperators expressed generally positive views of their involvement in the program and agreed that, overall, their involvement had been beneficial to them. Their evaluation of the final design that students submitted was generally positive, and the areas in which they felt students achieved particularly good results are detailed in an earlier section (*Learning Outcomes*).

Simultaneously, some cooperators expressed regret that their students' final design result was not a physical product but rather a design concept or a drawing and that they would "have to put in a ton more time to make this into something" (Matthew, 6). Other cooperators also expressed some regret that, in their opinion, the students' final design result would not be workable: "it's not usable. They missed a few key points" (Cameron, 6). These regrets seemed to relate, in some instances, to unclear expectations on the part of the industry cooperators, which they themselves acknowledged. Tim stated, "I didn't realize that there were actually different years [second, third, fourth] when I submitted these projects, and that was one of the surprises" (2). Matthew reflected, "here's me just hoping I've got this magical thing now that I can just slap on to my existing product and I'm off to the races to market it", while Art agreed, "[the students] being engineering students, I was thinking, 'okay, we'll get a nicely finished product'…But the concept's there and it's something we can build on" (15-16). Dave, the only participant to have been involved as a cooperator for more than one year, described his major learnings over the course of his involvement as adjusting his expectations on deliverables, and particularly with respect to what level of analysis was reasonable to expect.

Cooperators were very hesitant, though, to characterize these experiences with the students as disappointments: "disappointments just aren't the right word. It would have been nice to have been surprised with something great. But it wasn't and that's okay, too" (Cameron, 7). Tim succinctly summarized what emerged as issue for most cooperators: "my major disappointment wasn't the performance of the students. … It was in my lack of understanding of the program" (10, 15). The cumulative comments of the cooperators illuminated several areas of the program that lacked clarity, which could be summarized as communication issues. Several cooperators felt that their uncertainty began with the project recruitment and application process relative to the IDEA program (which is beyond the scope of this study). Cooperators indicated that they had been unaware that the results they may expect would differ depending on which year of the DT their project was assigned to, and suggested that instead of only the university assessing how complex their project was, "they should get a better feel [of the projects] by asking what we want out of it. Do we want a working product? Or do we want just a concept?" (Cameron, 8), and Matthew echoed these concerns, indicating his "surprise that there wasn't more interaction" (12). This participant, more than the others, felt that he lacked clarity on what his role was and what his responsibilities to the students were, down to the details of not knowing what length or nature of presentation was expected of him when he came to introduce the project to the students and not knowing how many months the students would be working on the project. Cooperators agreed that a personal contact prior to the term, as well as a written document that outlined their role and responsibilities in the process, and what their expectations should be, would go a long way to address these concerns. Randall noted that personal interaction "offers a lot" (p. 16) and could help clarify the cooperator's expectations to the university and vice versa. One cooperator's most significant disappointment in the program was "that there's nothing in place in the program to allow us to contract with these people" (Tim, 10) to take the project to completion. Another cooperator echoed this sentiment, that he was not sure whether after the course, students would be obligated to and/or interested in continuing to work on the project to bring it to completion (i.e. a finished product).

Several of the cooperators' suggestions for improving their experience arose directly out of these disappointments and have been alluded to above: clarify reasonable expectations for cooperators, clarify and document cooperators' role and responsibilities in the process, and build in a follow-up mechanism to continue the projects after the courses are complete. Additional suggestions included facilitating more interaction with the students, to address some cooperators' perceptions that the students were hesitant to contact them or unclear on how much they should be contacting their cooperator. Matthew suggested, "right after the initial acceptance of the project, have a wine and cheese, meet-and-greet, so that they could feel more comfortable coming and approaching us" (22). Finally, Matthew described that the students assigned to his project had contacted him to ask if they could go to the media with their design result. He indicated that if the university was able to facilitate media exposure, they should let potential cooperators know that as they recruit projects, stating "that's to my advantage, too. Those opportunities would make it even more appealing" (21).

The conversations with industry cooperators were also opportunities to gain insight into cooperators' perspectives of some of the students' concerns regarding industry involvement, without asking the cooperators directly. Some students expressed concern that they perceived no feedback and no follow-up from industry cooperators on their final design result, which led them to ask, "is industry giving us 'dud' projects?" (FG4-1, 5), i.e. projects in which they had no vested interest. Cooperators' comments indicated this did not appear to be the case. Matthew commented, "we have a list a mile long of things we could give them to do" (17) and Tim echoed, "it sounds like a trivial task, but nobody's built one anywhere in the world that works. So it's not as trivial a task as it sounds in the two paragraphs I laid out" (19). Randall also noted that since the project he provided involved many people in his organization, he needed "a final report that's well-written, …[because] you want to take the work that the students did and hand it to [others in the organization], … to build the case to do something. So that was important" (8-9). Other comments, highlighted earlier in this section, also indicate that cooperators generally carried high expectations for the process and the outcome.

Students had additional concerns that, at times, the presentation of the design problem by the industry cooperator lacked clarity, that cooperators may not recognize the time constraints that students have to work with, and that students would welcome more contact to and feedback from cooperators. Cooperators' earlier comments indicate that they, too, were unclear at times on what expectations were reasonable to hold and how much contact – both during and after the course - they should expect or initiate.

This section concludes the presentation of findings of participants' experiences in the DT in the 2002-2003 academic year. The final section of this chapter focuses on participants' perception on factors that facilitate the success of a DT model for learning design.

Transferability of the DT Model

At time of writing, some interest exists within the Faculty of Engineering to use the model of a course trilogy in other departments in the faculty to deliver design education. Within this context, it was appropriate to ask the NSERC Chair and the course instructors to reflect on what made the DT model successful in Biosystems Engineering, and what factors would be important to consider when transferring the model to other departments. In the responses of the participants, the concept of departmental culture emerged as the crucial factor in the success of the DT model in Biosystems Engineering, and a key factor to consider when potentially transferring the model to other departments.

The key components of the departmental culture of Biosystems Engineering that facilitated the DT were articulated as a team mentality among all faculty members (not just DT instructors), mirroring the dominant place of 'team' in the DT courses. These four participants all talked at length about the collegiality and support among the faculty: "we tend to talk to each other and respect each others' opinions" (Mark, 82). Barry referred to "the humanity of the persons" in the department, knowing that "I could turn to any one of a number of people and know that they were there for me. And in exchange I knew I was there for them" (77). All participants also referred to an openness in the department to "push the limits and try new things" (Gord, 97) and to support colleagues in their endeavours.

Participants mentioned numerous other components of the culture of Biosystems Engineering that they perceived to facilitate the success of the DT. Pedagogical components of department culture included an environment where teaching and spending time with students is seen as important, where instructors are willing to move away from the traditional power structure of the university classroom, where departmental technicians are involved in the learning process, and where non-technical aspects of engineering are valued equally to technical aspects. Other administrative factors to consider in transferring the model included a faculty coordinator or focal point and diversity in the professional backgrounds of the course instructors. Students and instructors referred to small size of the department and small class sizes as factors to consider in transferring the DT model. Larger cohorts in other departments would affect students' access to instructors and departmental technicians and the relative formality of the classroom environments. Demonstrating how physical facilities affect and change cultures, Barry expressed concern that in the recently-initiated process of building renovation, demolition, and re-construction, the Biosystems Engineering students will lose their dedicated student lounge space and share student lounge space with all other departments: "I worry about the new building, because the old lounge isn't going to be there, just a place to go sit and talk, which as professors, we've always been privileged to be invited in. We're going to have to work hard to maintain that culture in the new building" (43).

Several participants stated that the success of the DT came down to a departmental history of "thinking outside the box with respect to design education" (Mark, 81) and to "individuals who understand and see the benefit of doing [the DT]" (Gord, 97). For all participants, a key component of the Biosystems Engineering culture and a key component for success of the DT model in any other department was a fundamental departmental commitment to the process. While some of the cultural characteristics of Biosystems Engineering mentioned above may be perceived as counter-intuitive to the traditional academic structure and the traditional role of the academic faculty member, Mark believed that there's "no reason this couldn't work for any department" (84).

Given, though, that some of the factors deemed necessary for the success of the DT model appear to be counter-intuitive to existing departmental cultures, change theory and creating change was discussed with the NSERC Chair. Recognizing that change theory assumes that in a given population, 10% of individuals will be innovators, 80% will be followers, and 10% will be resistors, Barry's approach to facilitating change in the individual departments relates to creating structures that support innovators and allow them to work. Recognizing that a good proportion of innovators may be younger faculty, and therefore pre-tenure, Barry's comments demonstrated high concern that change must be facilitated without jeopardizing the professional tenure track of these individuals. Barry mentioned other factors that facilitate change, including "starting on a small scale and getting a few people working together" (78), the presence of a change agent as someone who is credible, well-known, and respected enough that people will embrace their vision, and the need to re-align academic reward systems (promotion and tenure).

This chapter has outlined the findings of data collection and data analysis, using the initial research questions and additional emerging themes to organize the presentation. The next chapter discusses these findings in relation to the preliminary conceptual framework created in Chapter 2 (Literature Review) and in relation to other relevant literature to highlight specific implications for teaching and learning.

Chapter 5:

Discussion

Discussion

The original research questions were designed to critically examine students', instructors', and industry cooperators' perceptions of teaching and learning engineering design in the DT courses:

- How do faculty, students, and industry cooperators of the DT conceptualize design?
- What are the critical goals of design education, as seen by faculty, students, and industry cooperators of the DT?
- What are effective teaching and learning strategies in design education, as seen by the faculty, students, and industry cooperators of the DT?
- To what extent do faculty, students, and industry cooperators of the DT think the current design education structure is successful?

The final research question was designed to explore the relationship between these perceptions and the preliminary conceptual framework for engineering design education, proposed in Chapter 2 Literature Review:

- To what extent do the DT courses, individually and as a trilogy, reflect elements of a comprehensive literature-based conceptual framework for design education? How can a comprehensive literature-based conceptual framework for design education be applied to improve the courses?

This chapter discusses the major features of the research findings relative to the conceptual framework that framed the study and highlights implications for teaching and learning engineering design.

Relationship of Findings to the Conceptual Framework

The preliminary conceptual framework included four constituent areas, each of which must relate to and be congruent with the three other areas to achieve an integrated whole (Figure 2.9). The four constituent areas are: Preparation, Structure, Administration, and Assessment & Evaluation, with some areas delineated further. A general impression emerged from data collection and analysis that although no one participant articulated all components of the conceptual framework, when taken together, the comments of the participant groups (the instructors' comments taken together; the students' comments taken together) presented multi-dimensional perspectives that were generally representative of the overall conceptual framework. Viewing the courses at the trilogy level highlights the team mentality that permeates the courses for the students, the instructors, and the department as each approach their respective tasks in teaching and learning. The contributions of individuals coupled with a team mentality lends to holistic perspectives of teaching and learning that are already reflected in the conceptual framework, where all individuals have a right and responsibility to contribute to a consolidated whole.

All four areas of the conceptual framework were deliberately considered in course planning in the DT and all instructors demonstrated a high level of awareness for complexity of the teaching and learning tasks in the DT. For example, the data also revealed a general sense of congruence between the individuals' approaches to teaching, goals for the courses, course content, teaching methods, and assignments, and assessment and evaluation strategies in their respective courses. Similarities between courses in teaching approaches (e.g. active learning; discovery learning), course goals (e.g.

communication skills; team skills), assignments (e.g. hands-on tasks; design projects), and evaluation strategies (e.g. peer evaluation) also indicated a general congruence between the four areas of the conceptual framework at the trilogy level.

Students' comments also indicated an awareness of the different nature of the DT in relation to other courses in the traditional undergraduate curriculum, and how this difference permeates all areas highlighted in the conceptual framework, from course goals to how class time is used to how student work is evaluated. Students' comments also revealed that their perceptions of congruence could be enhanced by knowing more the rationale behind instructors' choices and decisions (for example, why certain content is chosen) and by understanding the connections between various areas of the conceptual framework better (for example, the connection between the design projects and evaluation criteria). These comments point to issues of transparency and integration in teaching, which are discussed further in later sections.

Definition of Design

The conceptual framework proposed framing design education on a holistic definition of engineering design, consisting of a content dimension and a context dimension, representing methodology and perspective, respectively (Figure 2.1). The participants' responses reflected all elements of the definition of design in the conceptual framework. All participants initially referred to the internal content dimension, in which design is seen as a process or methodology with definable steps. In addition, all participants related, to some degree, to the external context dimension of the definition. Instructors demonstrated an internalized perspective of design as creative and iterative, and students demonstrated an emerging internalization of these elements. All participants reflected on the contextual information, such as economic and functional design parameters included in the definition, although instructors again demonstrated a more developed awareness of these elements. Finally, all participants demonstrated an outcomes-orientation in their design definition, in which the design culminates in a tangible end product. However, students' definitions tended to de-emphasize the design outcome, consistent with their stated experience that the 13-week DT courses are too short for them to carry the design process to completion.

Learning Outcomes

A second component of the Preparation area of the conceptual framework is the desired outcomes of engineering design education, organized into cognitive (knowledge and conceptual learning), behavioural (skills and competencies), and developmental (values and perspectives) outcomes (Figure 2.2). The instructors' and students' goals for the courses, the student outcomes recognized by both parties, and the industry cooperators' expectations of graduate engineers reflected almost all of the proposed outcome areas. In the cognitive domain, goals and outcomes included learning in engineering theories, methods, and conceptual tools and the design process. In the behavioural domain, goals and outcomes included developing design skills, creative problem solving, communication, and practical skills. In the developmental domain, goals and outcomes included developing team orientation, professional and ethical identity, and contextual awareness. A transition was also evident in that the second and third year instructors appeared to emphasize cognitive and behavioural goals, while the fourth year instructor appeared to emphasize behavioural and developmental goals.

Several of the outcome areas in the conceptual framework were not explicitly mentioned as goals by either instructors or students, including learning engineering science fundamentals (cognitive domain), learning analysis tools (behavioural domain), and developing a continuous learning orientation and leadership (developmental domain). However, the instructors and students communicated an assumption that the remainder of the undergraduate curriculum covered engineering science fundamentals and analysis skills, that students were assumed to be competent in these areas, and that the learning experiences in the DT used this knowledge and skill without developing it within the DT courses themselves. Industry cooperators also agreed that they assumed graduate engineers would have a fundamental knowledge of engineering science and analysis tools. In the developmental domain, fourth year students perceived leadership development within their DT experiences, although no instructors explicitly mentioned it as a course goal.

Instructors and industry cooperators also referred to general inter-personal skills as required (and achieved) outcomes for students, including flexibility, curiosity, self-directedness, and relational maturity. Although some of the developmental outcomes in the conceptual framework allude to inter-personal skills, the conceptual framework could be enhanced by adding it as a distinct outcome, as shown in Figure 5.1.

Cognitive Outcomes: **Knowledge & Conceptual Learning**	***Behavioural Outcomes:*** **Skills and Competencies**	***Developmental Outcomes*: Values and Perspectives**
Engineering science fundamentals: mathematics; basic sciences Engineering theories, methods, systems, languages, and conceptual tools Design process	Design skills Analysis in support of synthesis Creative problem-solving; holistic reasoning; heuristics Professional and personal communication Practical skills	Multi-disciplinary team orientation Professional and ethical identity Contextual, cultural, and global awareness Continuous learning orientation Leadership Interpersonal skills

Figure 5.1: Desired Outcomes of Engineering Design Education

The comparison of findings to the conceptual framework in the areas of design definitions and learning outcomes highlight instructor collaboration as an important teaching implication. The multi-faceted definition of design and three distinct learning outcome domains emphasize the need for instructors to communicate on how each dimension and domain will be developed and emphasized in the respective courses, in order for students to be exposed to a logical and multi-dimensional learning experience.

Learning Theory

Learning Theory was developed as a third component of the Preparation area of the conceptual framework. The Kolb Learning Cycle in an apprenticeship model was proposed as an appropriate model for engineering design education (see Figure 2.3). The Kolb Learning Cycle is seen as a formalized experiential framework in which to apply cognitive principles. The Kolb cycle accommodates Constructivist principles in emphasizing the role of experience in knowledge construction and where learning is active and situated in realistic contexts, and integrates individual and group learning experiences. The Kolb cycle also accommodates the idea of cognitive structures, in which knowledge is stored in the brain in an organized web, where minor elements of knowledge are subsumed under larger, more inclusive elements. New knowledge, including problem solving experience in design projects, is continually added to the cognitive structure and the web is re-organized to assimilate the new knowledge. Cognitive theory contends that logically meaningful material can only be learned in relation to previously learned material of relevant concepts and information, which in turn make possible new meanings and new connections in how knowledge is organized. This in turn enhances the retention and future application of knowledge (Zuber-Skerritt, 1992).

Viewing the Kolb cycle as an apprenticeship model transcends purely cognitive outcomes and situates theoretical knowledge in practical applications, to teach processes within the situations in which they are used. Such an apprenticeship model also cyclically exposes students to new information to develop cognitive structures. The DT structure by nature lends itself to an apprenticeship model, in that students have multiple opportunities within the courses and between the three courses to practice design processes. Within the courses, individual design assignments allow students to practice design process and skills toward their larger team design project. Between the courses, higher level students recognized the benefit of doing three design projects over three years. While no participants mentioned the Kolb Learning Cycle specifically, the comments of instructors reflected constructivist approaches to teaching, and the importance of experiential learning for students. Concepts of active learning, students creating their own knowledge and information, hands-on lab assignments, and the strong presence of design projects taken from real-life industry lend themselves to the constructivist approach in the DT. From a theoretical perspective, the DT functions on a solid pedagogical basis.

These cognitive and experiential approaches to learning can also be used to frame students' comments on their experiences. Students' perceptions of course content being at times disjointed, lacking context, and lacking relevance may be seen as a breakdown of the cognitive structure, in which new material cannot be assimilated to existing knowledge because the connections between the new material and students' existing knowledge are not clear to them. The teaching implication is that instructors can address knowledge assimilation by drawing numerous, varied, and explicit connections to existing knowledge as new material is being presented. Students also repeated a desire for improved connections between course content (lecture) and the design projects, such as lecture material being grounded in one of the design projects. This suggestion addresses the issue of knowledge assimilation, but also reflects both constructivist principles of learning as experiential and apprenticeship principles to teach processes in the situations in which they are used.

Embedded within the Kolb Learning Cycle (Figure 5.2) are four abilities through which the learner cycles: concrete experience (CO), reflective observation (RO), abstract conceptualization (AC), and active experimentation (AE). These abilities occur along two dimensions: information input (vertical axis – CO and AC) and information processing (horizontal axis – RO and AE).

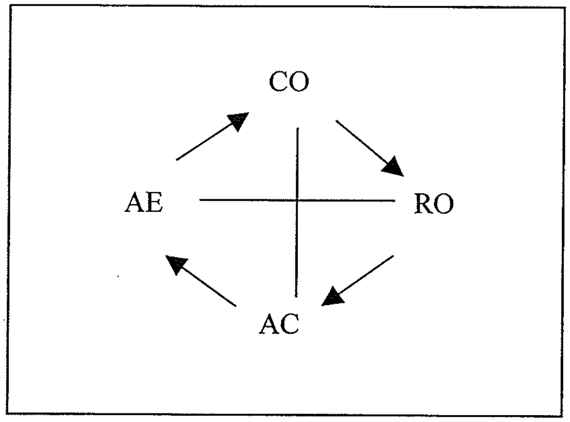


Figure 5.2: The Kolb Cycle

Svinicki & Dixon (1998) describe the process as *beginning* with the learner's personal involvement in a specific experience. The learner reflects on this experience to find its meaning. Out of this reflection, the learner draws logical conclusions and is prepared to integrate new theories and models; these experiences and new conceptual knowledge guide decisions and actions that lead to new concrete experiences. Students' desire to ground course content in a design project may also reflect their perception that in the DT the cycle often begins with abstract conceptualization (new information via lectures) and leads to active experimentation (applying concepts to design projects), but that the classroom process de-emphasizes concrete experience and reflective observation as starting points of learning. Even in interviews with instructors and students, a number of participants validated the role of reflective observation when they commented that the act of reflecting on the courses in the interview process and between interviews was a helpful exercise to organize their own thoughts, perceptions, and to confirm their intentions as participants in the courses.

Students' proposal to use design projects as a springboard for the course concepts also reflects Dewey's (1938) and Chickering's (1976) notions that learning – changes in knowledge, feelings, judgements, and skills - is the result of a person's involvement in an activity, looking back and evaluating it, determining what was useful or important to remember, and using this information to perform another activity. Students' comments analysed in relation to learning theory imply that instructors may wish to review the course structure to assess if and how design projects or other concrete experiences may more often become a starting point of learning experiences (in addition to their roles as applications for new learning), and how conscious reflection may more often be integrated into the learning process.

Course Structure

The second of four areas of the conceptual framework in Chapter 2 is course structure. The literature presents numerous and varied structural frameworks for engineering design courses, and the conceptual framework simply articulates that course structure should be a deliberate consideration in course planning, taking into account curriculum goals, desired outcomes, and student learning styles. The DT model is not reflected exactly in the literature reviewed. Its unique features include the combination of individual-content centric elements, team-content centric elements, and team-process centric elements as per Sheppard & Jenison (1997, 1997b) and the deliberate connections fostered between students and student teams in different cohorts. The structural concept of a trilogy was not reflected in any of the literature reviewed, though, and may be the defining feature of the DT model and a unique contribution to the literature base in the field.

Interviews with the NSERC Chair and the instructors confirmed the ways the DT enriched learning opportunities and processes and that the model has been conceptualized deliberately. The DT model is also subject to constant evolution in an effort to optimize the learning experiences and strengthen the experience of 'trilogy' for the students. Students' comments also provided some specific suggestions as to how this could be achieved, and alluded to the need for transparency on the part of instructors, and integration between the three courses. For example, instructors agreed that they needed to be vigilant about potential duplication of content between the courses. Students also suggested that the experience of 'trilogy' may be enhanced if they had greater confidence that the courses had been conceptualized as such and if they could perceive a flow, focus and overall vision in the courses' content, i.e. a syllabus for the DT as a whole. The design projects were also considered by both instructors and students as potential vehicles to strengthen the experience of 'trilogy' for students.

Administration

The third of four areas of the conceptual framework in Chapter 2 is course administration, or pedagogy. In this area, the role of the instructor and course delivery are considered. Figure 2.6 proposed an appropriate model of instructor–student interaction, elaborated from the Schön's (1987) model of coaching. The identities of the instructors and the perceptions of students appear to be congruent with a coaching model for instructor–student interaction, augmented with descriptors such as 'facilitator' and 'mentor'. The role of the student in the model as presented in the conceptual framework includes observing, listening, reflecting, imitating, applying, demonstrating, and integrating. Based on the earlier discussion in relation to learning theories, the model may be enhanced by adding the active components - 'experiencing' and 'reflecting' - to the role of student and, in teaching, focussing on ways to highlight the roles of experiencing and reflecting as starting points in the Kolb Learning Cycle.

The role of the instructor in the model as presented in the conceptual framework includes presenting new information, demonstrating, integrating, and critiquing. If any generalized impression emerged from the data, it may be that students' uncertainties and frustrations relative to the course material may be addressed through concerted efforts at *integrating*. Given instructors' and students' comments and the team focus in the courses, the model may be further enhanced by adding the roles of resourcing, facilitating, and empowering to the instructor's roles. Of course, the extent to which a given instructor can fulfill all of these roles is dependent on a variety of tangible and intangible factors, and students appreciated the diversity in each instructor's background and style. A final enhancement to the model of instructor-student interaction, based on the research findings, is the inclusion of more double-headed arrows to indicate reciprocal learning and the importance of instructors listening to and observing students to inform future decisions. The enhanced model of instructor-student interaction is shown in Figure 5.3.

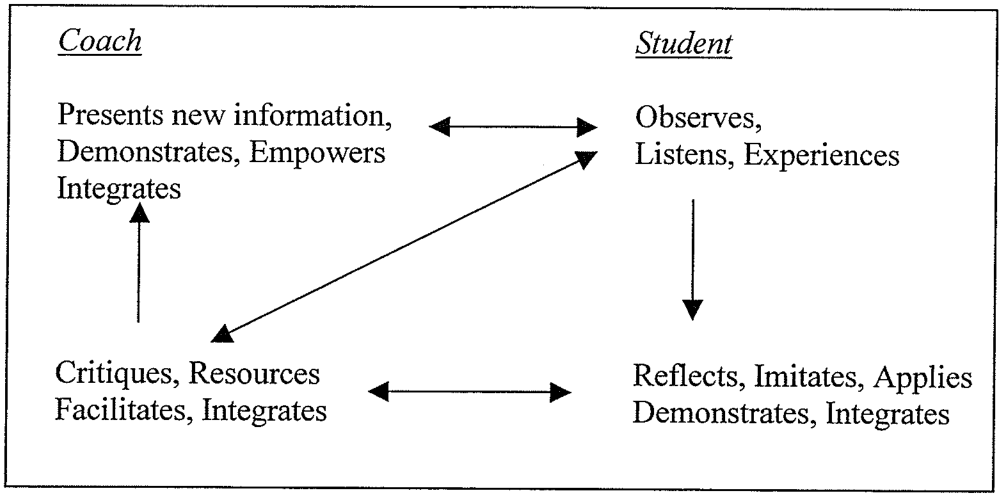


Figure 5.3: Model of Student-Faculty Interaction

Further to course administration, the conceptual framework proposed seven pedagogical foci as synthesized from the literature on important pedagogical considerations in engineering design education (Figure 2.7). The seven areas were design product (outcome), design process (experience & understanding), tools and media (e.g. projects), student behaviour and interaction, faculty behaviour and interaction, faculty-student interaction, and integration (through goals, contexts, assessment & evaluation). The findings suggest that all seven focal areas have been deliberately considered and are generally congruent with one another. Students' comments suggest that consideration of each area is not always *transparent* (for example, the emphasis on design process relative to design product), and that the *integration* of areas may be enhanced (for example, shifting assessment & evaluation emphases to reflect the experiential nature of the course and the scale of the design projects). A well-integrated component of the trilogy, recognized by instructors, students, and industry cooperators alike, is the progressive development of communication skills throughout all three courses. The teaching implications relative to course pedagogy relate to enhancing transparency, constantly assessing congruence of components with one another, and enhancing integration by drawing explicit connections for students between goals, content, assignments, and assessment & evaluation.

Assessment & Evaluation

The final area of the conceptual framework in Chapter 2 is assessment and evaluation. Assessment and evaluation begins with consideration of values, goals, and the purpose of assessment and evaluation, desired goals and outcomes, and instruments and measures. Assessment and evaluation focuses on design process, design product, and other student outcomes, and provides feedback for continuous improvement as well as data for evaluation. The findings suggest that instructors emphasize assessment processes in the classroom, and that student evaluation is consistent with course goals. Students' comments expressed several areas of frustration related to assessment and evaluation, including the use of individual written tests and exams to evaluate what they perceived to be essentially an active, team process; the weight of the design project in the evaluation scheme as disproportionate to its time and focus in the courses; and, a lack of transparency in criteria for marking design projects. These student perceptions are inextricably linked to perceptions related to course content (relevance and context) detailed earlier in this chapter and in the Findings (Chapter 4) and thus, teaching implications are also similar: the conceptual framework emphasizes congruence between and transparency of the desired goals, the evaluation instruments, and the areas being evaluated.

Assessment and evaluation can also be enhanced by consciously framing them as a learning tool and a student motivator. AAHE's Principles of Good Practice for Assessing Student Learning (Walvoord & Anderson, 1998) provide nine positions about assessment that is learning-oriented and encourages assessment and evaluation planning that is multi-dimensional, integrated, ongoing, and relates to educational values, goals, student experiences, and student outcomes.

No course model, regardless of how well conceptualized, will be entirely congruent in its delivery. Given areas of discontinuity highlighted in students' perceptions, the conceptual framework applied to the Design Trilogy nonetheless demonstrates a general sense of congruence between the Preparation, Structure, Administration, and Assessment & Evaluation components of the DT. The areas of discontinuity highlighted in the Findings (Chapter 4) and in earlier sections of this chapter give rise to broader implications for teaching, which are addressed in the following section.

Additional Implications for Teaching

The preceding discussion relating the findings to the conceptual framework alluded to key issues of transparency and integration in teaching. These issues are developed further in the following discussion on addressing points of 'disconnect' between students and instructors, and this discussion is framed more broadly in terms of the role of communication in organizing a curriculum for student learning.

Addressing Points of 'Disconnect'

Instructor and student responses in several areas highlighted points of 'disconnect', where instructors were planning and delivering a course in a certain way and with a distinct purpose in mind, yet that purpose and the desired outcome were not perceived by the students in the way the instructor(s) intended. One example was instructors' emphasis on the design process over the design product in the course (particularly in student evaluation). Instructors believed that many factors beyond the students' control may work against them if they were evaluated on the end product of their design project, and consistent with the course goals, the emphasis was placed on students' demonstrations of working through a design process. Students' perceptions included that the process was cut short and they were left with an unfulfilled curiosity in whether their end product was credible and meaningful to the instructor and the industry cooperator. Additional perceptions were that perhaps the projects were meaningless to the cooperators, since students' perceived little attention paid to whether the final design was workable or not. A second example of a 'disconnect' was in the selection of course content in the courses. Instructors' responses indicated that they often deliberated carefully on their course content, in terms of what to include and why it would be relevant and important for students in Biosystems Engineering. Students' perceptions included that the course content at times seemed disjointed, lacked relevance and context, and did not explicitly relate to the experiential parts of the course, particularly their design projects.

'Disconnects' may be viewed as communication issues, and two ideas used in interpersonal communication and conflict resolution can frame a response to 'disconnect'. The first idea, commonly quoted in teaching and learning literature, is *Make the Implicit Explicit*, or full disclosure of one's intentions and motivations. For example, in the interviews, I was able to ask which content each instructor chose for his course, and then probe into why he chose that particular content. The instructors were generally able to rationalize their choices, and often had very clear and well-developed rationale for the content choices. Similarly, instructors had developed ideas on the relative importance of design process and design product in the courses, which they clearly articulated when asked. By sharing these rationale with students, the instructor makes his implicit motivations, deliberations, and choices explicit to the students. The literature suggests that this transparency can be an effective motivating strategy for learners (McKeachie, Pintrich, Lin, Smith, & Sharma, 1998; Forsyth & McMillan, 1998).

A commonly used model in the conflict resolution field is *Intent-Action-Effect* (Haddigan, 2002), which can also frame interpersonal communication and address a point of 'disconnect'. In this model, every interaction includes both Jane's intent, Jane's action, and the effect of Jane's action on Rob. The intent and the effect are in the private domain, and only the action is in the public domain. Thus, Rob is usually not privy to Jane's intents, and Jane is often not privy to the real effects Rob experiences. Rob is likely to make assumptions about Jane's intentions (or lack thereof) based on the effect he experiences. Similarly, Jane is likely to assume that the effect on Rob is consistent with her intentions. To avoid communication breakdown, both the intent and the effect need to be brought into the public domain. In the context of 'disconnects' identified in the DT, the implications are that instructors may want to consider sharing their intentions with students as it relates to course content, teaching methods, assignments, and assessment and evaluation strategies, as well as developing additional ways to determine the effects on the students and the students' perceptions.

Developmental Transitions of Students

In addition to transparency in communication, another important factor in organizing a curriculum for student learning is planning an appropriate learning environment that takes into account the normal developmental transitions in students. Increasingly, student learning and classroom instruction are being re-conceptualized from a focus on the discipline and the instructor to a focus on the learner (Feldman & Paulsen, 1998 – a 700-page edited volume is an excellent compilation of such literature). New terms have entered the lexicon, including learner-centred education, learning communities, and joint knowledge construction. These concepts provide persuasive and comprehensive new frameworks for educational purpose, course content, instructional methods, and student and instructor roles. Similarly, the DT model in Biosystems Engineering also reflects a divergence from the traditional teaching and learning structure present to a large degree in the traditional undergraduate curriculum, which may be described as instructor-centred and discipline-centred. The organization of the DT, the intentions and actions of instructors, and the experiences and perceptions of students resonate with many of the components of Barr & Tagg's (1995) Learning Paradigm and Dressel & Marcus' (1998) framework of student-centred teaching. In both frameworks, emphases shift from delivering instruction and transferring knowledge to producing learning and eliciting student discovery. Students' roles include their own construction of information and active learning; faculty roles include designing learning environments and developing students' abilities.

When used in engineering, one must consider that in most other courses, students are likely presented with more traditional instructor- and discipline-centred teaching orientations. In the DT, the new student responsibilities, the changed role of the instructor, new approaches to constructing knowledge, and an approach to design that may appear – in the context of other learning experiences – inherently non-rigorous and unscientific can be frustrating for engineering students. This frustration was evident in the responses of the second-year cohort, while the responses of the higher level cohorts implied a transition in which they became more comfortable with these dimensions.

In addition, research initiated by W.G. Perry in 1970 and subsequently augmented by several educational researchers asserts that the intellectual development of college students usually moves from dualistic thinking in early years to relativistic thinking in later years (Kurfiss, 1998; MacKeracher, 1998). Dualistic thinkers perceive the instructor as an authority who communicates knowledge, knowledge as certain and absolute, and their own task to obtain information and demonstrate mastery. By contrast, relativistic thinkers perceive the instructor as an experienced guide or model, knowledge as being contextually validated, and their own tasks as thinking for oneself, sharing views, and creating own perspectives.

This combination – the DT reflecting a non-traditional learning model in engineering, and the normal intellectual developmental stages of undergraduates – highlights the potential pitfalls of adopting a student-centred orientation or a 'learning paradigm' perspective exclusively. The students' comments highlight the need for instructors the balance the roles of 'Guide on the Side' with some of the 'Sage on the Stage', and particularly the second year cohort seems vulnerable to uncertainty and frustration when the learning environment is obviously very different from their usual experiences. In interviews, the NSERC Chair referred to this phenomenon, citing his unanticipated realization that students needed to be conditioned to the new learning environment in design courses. To a certain degree, the structure of the DT already acknowledges this transition, in that the second year course has a much more structured pedagogy (defined course content, familiar teaching methods) than the fourth year course.

Facilitating Non-technical Skills and Behaviours

Implications for teaching also go beyond instructor- and course-level implications discussed earlier and move toward institutional considerations in using the DT model for learning engineering design. The differences between the DT model and a 'traditional' engineering curriculum extend to the DT's emphasis on developing non-technical skills and behaviours, and resources for instructors in facilitating these kinds of student learning often come from outside of engineering. The literature review and the research findings indicate that the goals and desired student outcomes of engineering design education go beyond cognitive knowledge goals. In the engineering literature, goals and desired outcomes are often distinguished as technical and non-technical goals, or hard skills and soft skills, and engineering faculties experiment to find models of learning that facilitate these dual domains. A particular challenge to the traditional curriculum is to find ways to effectively facilitate the non-technical or 'soft' skills of design. Most professional schools are similarly dealing with the imperative to find ways to teach professional competencies in addition to discipline knowledge.

It is interesting to note that many of the 'soft' skills of engineering design resonate with the Employability Skills 2000+ published by the Conference Board of Canada (www.conferenceboard.ca/nbec). The Employability Skills 2000+ are divided into fundamental skills, personal management skills, and teamwork skills, and are described as the skills one needs to enter, stay, and progress in employment. Fundamental skills include communication, information management, thinking, and problem-solving. Personal management skills include positive attitudes and behaviours, responsibility, adaptability, and continuous learning. Increasingly, non-engineering faculties and entire institutions are adopting the Employability Skills 2000+ or similar outcome frameworks as institution-wide learning outcomes. The implication for teaching is that engineering schools can draw on the experiences of peer institutions, but also network with other (non-engineering) professional schools and other institutions as they also work toward similar goals and outcomes.

Planning for Change

A final area that emerged as a key institutional implication was change theory. The comments of the NSERC Chair and the course instructors on factors to consider in potentially transferring the DT model to other engineering departments within the institution alluded to the complexity of implementing change successfully. Most of the participants' comments were summarized as factors related to the role of departmental culture in facilitating success. Farmer (1990) defines culture as the shared set of tacit "assumptions, beliefs and feelings" of members that "shapes decisions, actions, and communication on both an operational and symbolic level" (p. 8), and change theorists agree that failure to understand the interaction of organizational culture with contemplated change strategies may mean failure of the strategies themselves. Ewell (1997) reflects this understanding in his assertion that change must be systemic, requires fundamental shifts in perspective, and requires people to re-learn their own roles.

Also consistent with change theory literature, the NSERC Chair and the course instructors referred to the commitment of the department and the support of departmental colleagues and administrators in facilitating the success of the DT. Farmer (1990) and Ewell (1997) agree that conscious, consistent, and committed leadership are essential for change. Other conditions are also considered necessary for successful change. One such condition is the presence of a change agent who understands the culture, resources, and politics of an organization and acts as catalyst, process helper, resource linker, confidence builder, and solution giver. A condition of trust (between faculty and administrators) and effective planning are also essential conditions for change. Finally, implementation strategies should include participatory processes, the use of information in decision-making, incremental changes, preparation, incentives, and a focus on winning support from a critical mass (Farmer, 1990; Ewell, 1997).

Although reluctant to identify himself in that way, the NSERC Chair appears to reflect most of the qualities and behaviours of a change agent in the Faculty of Engineering at Western Canadian University. His comments also demonstrated awareness of most of the critical conditions for successful change. These conditions and strategies highlighted by Farmer (1990) underscore the complexity of organizing curriculum change, although a body of literature and on-campus faculty development professionals are available to assist any department serious about the task. Any transfer of the DT model to other engineering departments will necessarily carry the unique stamp of the department (in subject matter) and of the instructor(s). The evolution of the DT in Biosystems Engineering demonstrates that the model is both fluid and robust. The most important considerations for transferring the model transcend 'what do we teach' and 'what will the assignments be', and rather relate directly to curriculum constraints such as human, financial, and facility resources and to change theory.

In summary, a comparison of findings to the preliminary conceptual framework reveals a high degree of congruence, and the findings highlight several additional enhancements to the conceptual framework. Key findings related to student perceptions in course planning and course delivery are reflected in the conceptual framework as issues of transparency and integration. These issues give rise to broader teaching implications at both at the instructor- and course-level, as well as at the institutional level. Teaching implications include communication and collaboration between and among instructors and students, awareness of normal developmental transitions in undergraduate students, awareness of the differences in the DT model relative to the 'traditional' engineering curriculum, awareness of the similarities in desired learning outcomes relative to other professional schools, and the body of change theory that can guide successful implementation of the DT model in new environments. The final chapter addresses a few remaining requirements of a qualitative research procedure, namely by reflecting on my personal learnings in the process, providing a statement of limitations, and proposing questions for additional research.

Chapter 6:

Concluding Comments

Statement of Limitations

Qualitative research is an interactive and interpretive process, and the findings and discussion need to be read in the context outlined in Chapter 3 Methodology, particularly as it relates to the theoretical perspective brought to the research and the role and background of the researcher. It should be understood that the findings relate the experiences and perceptions of the particular individuals who voluntarily participated in the study at Western Canadian University, as experienced in the 2002-2003 academic year. As such, the findings and resulting discussion and implications are not necessarily generalizable to design education in other contexts, and the potential effects of self-selection among student participants should be noted. If self-selection were a dominant factor in this research, one would expect the students' comments to be overly one-sided in either a positive or negative way. The findings reveal that students' comments were multi-dimensional and diverse, and this provides comfort that self-selection did not compromise the study.

Questions for Further Research

Since generalizability to broader contexts is not an express purpose of qualitative research, it would be interesting and worthwhile to carry out parallel studies of design education models, to investigate differences and similarities in participants' perceptions of teaching and learning engineering design. These other contexts could span other institutions, or the same institution at different points in time.

The comments of the six industry cooperators revealed areas of concern related to the administration of their involvement in the DT courses. A collaborative and mutually beneficial relationship to industry partners is very important to the Faculty of Engineering. As such, it would be worthwhile to gather data from a larger group of industry cooperators, to understand their experiences and perceptions more fully, to enhance cooperators' involvements in university courses, and to enhance connections between industry and the university generally.

Personal Reflections

Qualitative research is an interaction between the researcher, the participants, and the research setting. Thus, the researcher may be influenced by the process, and it is appropriate to outline some of my key reflections relative to this influence. The process of planning this study, collecting the data through interviews, analyzing the results, and writing have given me ample opportunities to reflect on my own experiences as a student in a former evolution of the DT courses at Western Canadian University. The process also allowed me to contextualize some of my experiences – and in particular, my frustrations – in professional practice as a design engineer, in light of what I learned about engineering design in this study. In particular, I recognized myself in the second-year cohort when the students expressed a combination of frustration and uncertainty about design being 'unscientific' and 'lacking a theory base'. As an undergraduate student, I too intuitively characterized engineering as dealing with linear processes, right-or-wrong outcomes, black-and-white solutions, and I, too, experienced the DT courses as a marked departure from these expectations. As a student, I was good at the 'traditional' curriculum and preferred to learn individually rather than in the context of a group or team, and I failed to understand the motivations and intentions of the DT.

As this study progressed, I felt a great deal of admiration for the higher-level student cohorts in the way they had seemed to overcome this uncertainty and ambiguity and embraced the 'otherness' of engineering design. When I reflected on my own experiences as an undergraduate student, I identified that I had never successfully made that transition in university, despite being academically successful in the DT and other courses.

It was after a number of years in engineering practice that I began to glimpse the true nature of engineering design as creative and artistic, and that I developed the self-awareness to see that I had not developed those skills in university and needed to find ways to develop them at that point in time. I also began to recognize that many of my frustrations about my job – just as everyone carries some frustrations about their job – were rooted in feeling increasingly unsure of what skills and abilities a successful engineer needed, or 'what *is* an engineer, exactly?', and feeling that my undergraduate engineering education had not *fully* prepared me for practice. The process of this study allowed me to acknowledge and understand the feelings and disparate pieces of awareness that have been a part of my life over the past 12 years, and to contextualize them as being part of a necessary learning process that began in second year of my undergraduate degree and continues to be ongoing.

In addition to increased self-awareness as a result of this study, the interview process also allowed me to learn about the personal and professional histories of the participants, particularly the NSERC Chair and the three instructors. I felt privileged to hear about some of the professional and personal struggles and insights of these individuals. I felt energized after the discussions of engineering design and engineering practice on a conceptual level. I felt welcomed as a colleague, to share my own experiences with the participants. These factors, and others, nurtured my self-image and allowed me to overcome some of the personal hurts that lingered from my last long-term employment experience. In that sense, I experienced personal restoration through the research process.

Conclusion

This study has outlined a qualitative research process that examined students', instructors', an administrator's, and industry cooperators' perceptions of engineering design education in the Design Trilogy course model in a Biosystems Engineering department at a large, research-intensive Canadian university. The research questions were developed to discover participants' concepts of engineering design, critical goals of design education, effective teaching and learning strategies in design education, and reflections on the Design Trilogy structure. The study was grounded in one-on-one and focus group interviews for data collection and inductive data analysis. In addition, the researcher generated a preliminary conceptual framework for engineering design education from the relevant literature and highlighted comparisons and departures between the findings and the conceptual framework that framed the study.

The findings yielded rich and complex understandings of teaching and learning engineering design on the part of the participants, with many areas of common perceptions between participant groups and congruence with the conceptual framework. The findings also illuminated instances where students' perceptions and experiences did not correspond to instructors' intentions, and where industry cooperators' perceptions and experiences did not correspond to the university's intentions. These findings were framed in discussions of transparency and integration in teaching, collaboration between instructors, communication between instructors and students and between the university and industry cooperators, awareness of the unique nature of the DT model within the undergraduate engineering curriculum and the impact on students, and the institutional considerations (such as organizational culture) that affect the success of teaching and learning endeavours.

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Appendix A: List of Abbreviations

ABET	Accreditation Board for Engineering and Technology (American)
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
CEAB	Canadian Engineering Accreditation Board
CCPE	Canadian Council of Professional Engineers
DT	Biosystems Engineering Design Trilogy (courses 34.258, 34.358, and 34.458) offered by the Department of Biosystems Engineering, Western Canadian University (a pseudonym)
EC2000	Engineering Criteria 2000 (published by ABET)
IEEE	Institute of Electrical and Electronics Engineers
NRC	National Research Council (American)
NSERC	Natural Sciences and Engineering Research Council (Canadian)
US	United States

Appendix B
Entry Documents & Request for Informed Consent

Letter to Design Trilogy Students – Preliminary Letter

Project Title:	A Qualitative Analysis of Engineering Design Education in the Department of Biosystems Engineering, University of (xxx)
Researcher:	Marcia Friesen, B.Sc. (Agricultural Engineering), P.Eng., M.Ed. student
Sponsor:	None. This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies).

Allow me to introduce myself as the researcher in this project. I am a 1995 graduate of Agricultural Engineering at the University of (xxx). I spent 1995 – 2000 as a design engineer in engineering consulting in the areas of environment, agriculture and agri-business, and completed the requirements for professional engineering registration (P.Eng.). In 2000, I returned to the university for graduate studies in education. My goal continues to be to find applications for my graduate work in the Faculty of Engineering. This thesis project, focussed on the Design Trilogy in Biosystems Engineering, is one such application. In addition to graduate work, I have had opportunities to teach sessionally in the Faculty of Engineering and to work as a research assistant in the Design Engineering department.

I am interested in exploring how engineering design education is conceptualized within the Design Trilogy (34.258, 34.358, and 34.458 (formerly 34.214, 34.326, and 34.413, respectively)) in Biosystems Engineering here at the U of (x). Specifically, my purpose in this study is to understand participants' conceptualizations of teaching and learning in engineering design education. The objectives of the study are to (1) understand design participants' views, opinions, ideas, and perceptions of design and engineering design education in the Design Trilogy; and (2) to understand how these perceptions guide your role as students in the Design Trilogy. To fulfill these objectives, I am recruiting students of the Design Trilogy courses for focus group interviews.

Should you agree to participate, you will participate in two focus group interviews of one-hour duration each. The interviews will be scheduled for September and December, 2002, in order to capture the beginning and end of the term in which the Design Trilogy courses are taught. I will be holding separate focus group interviews with the second-, third-, and fourth-year classes respectively. Focus groups have been defined as a carefully planned, informal discussion designed to obtain perceptions on a defined area of interest (design education) in a permissive, non-threatening environment. A focus group is conducted with up to twelve people at once. The discussion is relaxed, comfortable, and often enjoyable to the participants as they share ideas and perceptions. The purpose of a focus group is to gather data on the opinions, attitudes, and perceptions of the group. The focus group is not a process to reach consensus, to provide recommendations, or to make decisions.

The focus group sessions will be held at a time and location on campus suitable to the group. The interview strategy will follow qualitative focus group interviewing norms; as opposed to a structured question and answer session, the format will be conversational and relaxed. I will make reference to a prepared interview guide with open-ended questions to guide our conversation. My role in the interview will be to provide an atmosphere in which you feel comfortable disclosing your feelings, perceptions, and opinions relative to design and engineering design education. I will have an assistant present to take detailed notes during the focus group session. My analysis of the session will be based on the assistant's written notes. As a back-up only, I will also audiotape the focus group session. Should you desire, drafts of the thesis can also be provided to you for review and comment. The identity of focus group participants will be kept confidential by myself and the assistant moderator. In the notes made during the focus group session, each participant will be identified only by a letter or number corresponding to your seating arrangement in the group.

As the project progresses, I may also ask to see examples of your work in order to clarify or confirm some of the things I think I'm hearing and learning from the focus group sessions. Examples of your work may be lecture notes, assignments, projects, and tests. It is entirely up to you whether you wish to provide these to me, and there is no penalty for not providing examples of your work. If you choose to provide examples of your work, the amount and nature of the work that you provide is left to your discretion. I also encourage you to erase your name, student number, any other personal identifiers, and any instructor's comments from the work before you give it to me. Once the project is complete, I will return the work to you or destroy it, as per your preference.

Given the nature of the study, I anticipate only minimal potential of risk to participants. Before providing written consent, however, you should be aware that you would have the right to withdraw any of your comments or withdraw completely from the study at any time, and that any disclosures or data you provide are held in complete confidence. To preserve confidentiality, pseudonyms will be used in all notes, transcripts, and reports associated with the study. An explicit assurance of confidentiality will be given prior to the focus group interview session. Neither the researcher, the assistant moderator, nor the focus group members will reveal the identity of other focus group participants. In the final report, all quotations, citations, or paraphrases will be made generic with respect to unique personal features or identifiers, including but not limited to your gender, age, ethnicity, and exact position in the organization. All data collected in the course of the study will be held at my home. At the completion of the study, all audiotapes will be destroyed. I anticipate completing this study in summer, 2003. Focus group notes will be kept in a secure location at my home until any articles arising out the research have been accepted for publication; this period will not exceed five years, after which all focus group notes will be destroyed.

I should also let you know that no compensation is being offered for your participation, although I will likely provide refreshments during the focus group interview sessions. You should also be aware that your participation in this study is completely independent of (unrelated to) your grade in the Design Trilogy course (34.258, 34.358, or 34.458). You will not be rewarded nor penalized in the Design Trilogy course for your decision to participate or not to participate in the focus group sessions.

Should you have questions at any point, you are encouraged to contact me (e-mail and home phone given below), or my thesis advisor. My advisor is Dr. Lynn Taylor, Ph.D., (address), University of (xxx), telephone (xxx-xxxx), fax (xxx-xxxx), and email (xxx@xxx.ca).

If you are interested in participating in this research by attending two focus group sessions (one in September and one in December), please contact me by **September 13, 2002**. I can be reached at:

Home phone

I am looking for up to eight participants per class. After September 13, I will contact all interested participants to arrange a suitable time and place for the first focus group session in September, 2002. I will also provide you with a more detailed letter outlining the research as well as a written consent form, which you should sign and bring to the first focus group session.

Please leave me:
- your name
- an e-mail address or phone number where you can be reached
- which course you are currently in (34.258, 34.358, or 34.458)

Sincerely,

Marcia Friesen, P.Eng.
M.Ed. Student

Letter to Design Trilogy Students – Second Letter

Project Title:	A Qualitative Analysis of Engineering Design Education in the Department of Biosystems Engineering, University of (xxx)
Researcher:	Marcia Friesen, B.Sc. (Agricultural Engineering), P.Eng., M.Ed. student
Sponsor:	None. This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies).

16 September 2002

____
c/o 438 Engineering Bldg.
Faculty of Engineering, University of (xxx)
(city, province, postal code)

Dear ______________________:

Thank you for considering participation in this research study. This letter is provided to you to outline the purpose and nature of the study, to formally request your participation in the study, and to obtain your written informed consent as a participant.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies). Allow me to introduce myself as the researcher in this project. I am a 1995 graduate of Agricultural Engineering at the University of (xxx). I spent 1995 – 2000 as a design engineer in engineering consulting in the areas of environment, agriculture and agri-business, and completed the requirements for professional engineering registration. In 2000, I returned to the university to pursue a long-standing interest in graduate studies in education. My goal continues to be to find applications for my graduate work in the Faculty of Engineering. This thesis project, focussed on the Design Trilogy in Biosystems Engineering, is one such application. In addition to graduate work, I have had opportunities to teach sessionally in the Faculty of Engineering and to work as a research assistant in the Design Engineering department.

The following is a brief context for this research. Nationally and internationally, undergraduate engineering programs have been criticized for the perceived lack of design skills and design competencies of engineering graduates. The University of (xxx) (U of (x)), like other universities in Canada and U.S., has taken these criticisms seriously and has implemented a number of new initiatives to enhance and improve design education for engineering undergraduates. Such new initiatives include the NSERC Design Chair, the Design Engineering department, the Engineer-in-Residence program, and curriculum modifications to introduce design into the first year. The Design Trilogy in Biosystems Engineering is a longer-standing initiative, which is now being viewed with renewed interest. The potential exists to transplant this model of a design course trilogy into other departments within the Faculty of Engineering.

I am interested in exploring how engineering design education is conceptualized within the Design Trilogy in Biosystems Engineering (34.258, 34.358, and 34.458 (formerly 34.214, 34.326, and 34.413)) here at the U of (x). Specifically, my purpose in this study is to understand participants' conceptualizations of teaching and learning in engineering design education. The objectives of the study are to (1) understand design participants' views, opinions, ideas, and perceptions of design and engineering design education in the Design Trilogy; and (2) to understand how these perceptions guide your role as students in the Design

Trilogy. To fulfill these objectives, I am recruiting Design Trilogy instructors, the NSERC Chairholder, and industrial clients of the Design trilogy for one-on-one interviews, and recruiting students of the Design Trilogy courses for focus group interviews.

Should you agree to participate, you will participate in two focus group interviews of one-hour duration each. The interviews will be scheduled for September and December, 2002, in order to capture the beginning and end of the term in which the Design Trilogy courses are taught. I will be holding separate focus group interviews with the second-, third-, and fourth-year classes respectively. Focus groups have been defined as a carefully planned, informal discussion designed to obtain perceptions on a defined area of interest (design education) in a permissive, non-threatening environment. A focus group is conducted with up to twelve people at once. The discussion is relaxed, comfortable, and often enjoyable to the participants as they share ideas and perceptions. The purpose of a focus group is to gather data on the opinions, attitudes, and perceptions of the group. The focus group is not a process to reach consensus, to provide recommendations, or to make decisions.

The focus group sessions will be held at a time and location on campus suitable to the group. The interview strategy will follow qualitative focus group interviewing norms; as opposed to a structured question and answer session, the format will be conversational and relaxed. I will make reference to a prepared interview guide with open-ended questions to guide our conversation. My role in the interview will be to provide an atmosphere in which you feel comfortable disclosing your feelings, perceptions, and opinions relative to design and engineering design education. I will have an assistant present to take detailed notes during the focus group session. My analysis of the session will be based on the assistant's written notes. As a back-up only, I will also audiotape the focus group session. Should you desire, drafts of the thesis can also be provided to you for review and comment. The identity of focus group participants will be kept confidential by myself and the assistant moderator. In the notes made during the focus group session, each participant will be identified only by a letter or number corresponding to your seating arrangement in the group.

As the project progresses, I may also ask to see examples of your work in order to clarify or confirm some of the things I think I'm hearing and learning from the focus group sessions. Examples of your work may be lecture notes, assignments, projects, and tests. It is entirely up to you whether you wish to provide these to me, and there is no penalty for not providing examples of your work. If you choose to provide examples of your work, the amount and nature of the work that you provide is left to your discretion. I also encourage you to erase your name, student number, any other personal identifiers, and any instructor's comments from the work before you give it to me. Once the project is complete, I will return the work to you or destroy it, as per your preference.

Given the nature of the study, I anticipate only minimal potential of risk to participants. Before providing written consent, however, you should be aware that you have the right to withdraw any of your comments or withdraw completely from this study at any time, and that any disclosures or data you provide are held in complete confidence. To preserve confidentiality, pseudonyms will be used in all notes, transcripts, and reports associated with the study. An explicit assurance of confidentiality will be given prior to the focus group interview session. Neither the researcher, the assistant moderator, nor the focus group members will reveal the identity of other focus group participants. In the final report, all quotations, citations, or paraphrases will be made generic with respect to unique personal features or identifiers, including but not limited to your gender, age, ethnicity, and exact position in the organization. All data collected in the course of the study will be held at my home. At the completion of the study, all audiotapes will be destroyed. I anticipate completing this study in summer, 2003. Focus group notes will be kept in a secure location at my home until any articles arising out the research have been accepted for publication; this period will not exceed five years, after which all focus group notes will be destroyed.

I should also let you know that no compensation is being offered for your participation, although I will likely provide refreshments during the focus group interview sessions. You should also be aware that your participation in this study is completely independent of (unrelated to) your grade in the Design Trilogy course (34.258, 34.358, and 34.458). You will not be rewarded nor penalized in the Design Trilogy course for your decision to participate or not to participate in the focus group sessions.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. I can be contacted as follows:

Marcia Friesen
(city, province, postal code)

Tel (home)
Email

My thesis supervisor can be contacted as follows:

K. Lynn Taylor, Ph.D.
Room 220 Sinnott Bldg.
University of (xxx)

Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

Other committee members are:

M.G. (Ron) Britton, P.Eng., Ph.D.
Rm. 107 Engineering Bldg.
University of (xxx)

Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

David Kirby, Ph.D.
Room 220 Sinnott Bldg.
University of (xxx)

Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project, you may contact the above-named persons or the Human Ethics Secretariat at 474-7122. A copy of this consent form has been given to you to keep for your records.

Sincerely,

Marcia Friesen, P.Eng.
M.Ed. Student

Please sign below to indicate your informed written consent to participate in this study, and bring this consent form to our first focus group session.

Participant's signature	Date
Researcher and/or Delegate's Signature	Date

Letter to Design Trilogy Instructors

Project Title:	A Qualitative Analysis of Engineering Design Education in the Department of Biosystems Engineering, University of (xxx)
Researcher:	Marcia Friesen, B.Sc. (Agricultural Engineering), P.Eng., M.Ed. student
Sponsor:	None. This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies).

26 July 2002

(name)
c/o 438 Engineering Bldg.
Faculty of Engineering, University of (xxx)
(city, province, postal code)

Dear (name):

Thank you for considering participation in this research study. This letter is provided to you to outline the purpose and nature of the study, to formally request your participation in the study, and to obtain your written informed consent as a participant.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies). Allow me to introduce myself as the researcher in this project. I am a 1995 graduate of Agricultural Engineering at the University of (xxx). I spent 1995 – 2000 as a design engineer in engineering consulting in the areas of environment, agriculture and agri-business, and completed the requirements for professional engineering registration. In 2000, I returned to the university to pursue a long-standing interest in graduate studies in education. My goal continues to be to find applications for my graduate work in the Faculty of Engineering. This thesis project, focussed on the Design Trilogy in Biosystems Engineering, is one such application. In addition to graduate work, I have had opportunities to teach sessionally in the Faculty of Engineering, and I continue to be employed as a research assistant within the Design Engineering department.

The following is a brief context for this research. Nationally and internationally, undergraduate engineering programs have been criticized for the perceived lack of design skills and design competencies of engineering graduates. The University of (xxx) (U of (x)), like other universities in Canada and U.S., has taken these criticisms seriously and has implemented a number of new initiatives to enhance and improve design education for engineering undergraduates. Such new initiatives include the NSERC Design Chair, the Design Engineering department, the Engineer-in-Residence program, and curriculum modifications to introduce design into the first year. The Design Trilogy in Biosystems Engineering is a longer-standing initiative, which is now being viewed with renewed interest. The potential exists to transplant this model of a design course trilogy into other departments within the Faculty of Engineering.

I am interested in exploring how engineering design education is conceptualized within the Design Trilogy in Biosystems Engineering (34.214, 34.326, and 34.413) here at the U of (x). Specifically, my purpose in this study is to understand participants' conceptualizations of teaching and learning in engineering design education. The objectives of the study are to (1) understand design participants' views, opinions, ideas, and perceptions of design and engineering design education in the Design Trilogy; and (2) to understand how these perceptions guide your role(s) as a faculty member in the Design Trilogy. To fulfill these objectives, I am recruiting Design Trilogy instructors, the NSERC Chairholder, and industrial clients of the Design trilogy for one-on-one interviews, and recruiting students of the Design Trilogy courses for focus group interviews.

Should you agree to participate, you and I will engage in three face-to-face interviews of one-hour duration each. The interviews will be scheduled for August, October, and December, 2002, in order to capture the beginning, middle, and end of the term in which the Design Trilogy courses are taught. The interviews will be held at a time and location suitable for you. The interview strategy will follow qualitative interviewing norms; as opposed to a structured question and answer session, the format will be conversational and relaxed. I will make reference to a prepared interview guide with open-ended questions to guide our conversation. My role in the interview will be to provide an atmosphere in which you feel comfortable disclosing your feelings, perceptions, and opinions relative to design and engineering design education.

Consistent with qualitative interviewing norms, I will audiotape the interview and transcribe the audiotape immediately after the interview (within 24 hours). The transcript will also include notes about non-verbal features of the situation (such as location, atmosphere, tone, body language) taken from my written notes during the interview session. A copy of the transcript will be provided to you in either hard copy or electronic form (as per your preference), for your review. You will be invited to make additions and deletions to the transcript and return your comments to me. Should you desire, drafts of the thesis can also be provided to you for review and comment.

As the project progresses, I may also ask to see examples of your course materials in order to clarify or confirm some of the things I think I'm hearing and learning from the interview sessions. Examples of course materials may be course syllabi, lecture notes, assignment instructions, test instructions, and exam instructions. It is entirely up to you whether you wish to provide these to me. If you choose to provide examples of your course materials, the amount and nature of the material that you provide is left to your discretion. Once the project is complete, I will return the materials to you or destroy it, as per your preference.

Given the nature of the study, I anticipate only minimal potential of risk to participants. Before providing written consent, however, you should be aware that you have the right to withdraw any of your comments or withdraw completely from this study at any time, and that any disclosures or data you provide are held in complete confidence. To preserve confidentiality, pseudonyms will be used in all notes, transcripts, and reports associated with the study. An explicit assurance of confidentiality will be given prior to the interview session. In the final report, all quotations, citations, or paraphrases will be made generic with respect to unique personal features or identifiers, including but not limited to your gender, age, ethnicity, and exact position in the organization. You will be consulted on all excerpts or quotations used in the final writing. All data collected in the course of the study will be held at my home. Transcripts of our audiotaped interview will be shared only with yourself. At the completion of the study, all audiotapes will be destroyed. I anticipate completing this study in summer, 2003. Interview transcripts will be kept in a secure location at my home until any articles arising out the research have been accepted for publication; this period will not exceed five years, after which all interview transcripts will be destroyed. I should also let you know that no compensation is being offered for your participation.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. I can be contacted as follows:

Marcia Friesen

(city, province, postal code)

Tel (home)
Email

My thesis supervisor can be contacted as follows:

K. Lynn Taylor, Ph.D.
Room 220 Sinnott Bldg.
University of (xxx)
Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

Other committee members are:

M.G. (Ron) Britton, P.Eng., Ph.D.
Rm. 107 Engineering Bldg.
University of (xxx)
Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

David Kirby, Ph.D.
Room 220 Sinnott Bldg.
University of (xxx)
Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project, you may contact the above-named persons or the Human Ethics Secretariat at 474-7122. A copy of this consent form has been given to you to keep for your records.

Sincerely,

Marcia Friesen, P.Eng.
M.Ed. Student

Please sign below to indicate your informed written consent to participate in this study:

Participant's signature Date

Researcher and/or Delegate's Signature Date

Letter to NSERC Chairholder

Project Title:	A Qualitative Analysis of Engineering Design Education in the Department of Biosystems Engineering, University of (xxx)
Researcher:	Marcia Friesen, B.Sc. (Agricultural Engineering), P.Eng., M.Ed. student
Sponsor:	None. This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies).

23 July 2002

(name)
107A Engineering Bldg.
Faculty of Engineering, University of (xxx)
(city, province, postal code)

Dear (name):

Thank you for considering participation in this research study, as expressed in our earlier conversations and in your communication with Dr. (xxx), Biosystems Engineering department head. This letter is provided to you to outline the purpose and nature of the study, to formally request your participation in the study, and to obtain your written informed consent as a participant.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies). Allow me to introduce myself as the researcher in this project. I am a 1995 graduate of Agricultural Engineering at the University of (xxx). I spent 1995 – 2000 as a design engineer in engineering consulting in the areas of environment, agriculture and agri-business, and completed the requirements for professional engineering registration. In 2000, I returned to the university to pursue a long-standing interest in graduate studies in education. My goal continues to be to find applications for my graduate work in the Faculty of Engineering. This thesis project, focussed on the Design Trilogy in Biosystems Engineering, is one such application. In addition to graduate work, I have had opportunities to teach sessionally in the Faculty of Engineering, and I continue to be employed as a research assistant within the Design Engineering department.

The following is a brief context for this research. Nationally and internationally, undergraduate engineering programs have been criticized for the perceived lack of design skills and design competencies of engineering graduates. The University of (xxx) (U of (x)), like other universities in Canada and U.S., has taken these criticisms seriously and has implemented a number of new initiatives to enhance and improve design education for engineering undergraduates. Such new initiatives include the NSERC Design Chair, the Design Engineering department, the Engineer-in-Residence program, and curriculum modifications to introduce design into the first year. The Design Trilogy in Biosystems Engineering is a longer-standing initiative, which is now being viewed with renewed interest. The potential exists to transplant this model of a design course trilogy into other departments within the Faculty of Engineering.

I am interested in exploring how engineering design education is conceptualized within the Design Trilogy in Biosystems Engineering (34.214, 34.326, and 34.413) here at the U of (x), and more broadly. Specifically, my purpose in this study is to understand participants' conceptualizations of teaching and learning in engineering design education. The objectives of the study are to (1) understand design participants' views, opinions, ideas, and perceptions of design and engineering design education; and (2) to understand how these perceptions guide your role(s) in planning and delivering engineering design education. To fulfill these objectives, I am recruiting Design Trilogy instructors, the NSERC Chairholder, and industrial clients of the Design trilogy for one-on-one interviews, and recruiting students of the Design Trilogy courses for focus group interviews.

Should you agree to participate, you and I will engage in two to three face-to-face interviews of one-hour duration each. The interviews will be scheduled for August and December, 2002, at a time and location suitable for you. The interview strategy will follow qualitative interviewing norms; as opposed to a structured question and answer session, the format will be conversational and relaxed. I will make reference to a prepared interview guide with open-ended questions to guide our conversation. My role in the interview will be to provide an atmosphere in which you feel comfortable disclosing your feelings, perceptions, and opinions relative to design and engineering design education.

Consistent with qualitative interviewing norms, I will audiotape the interview and transcribe the audiotape immediately after the interview (within 24 hours). The transcript will also include notes about non-verbal features of the situation (such as location, atmosphere, tone, body language) taken from my written notes during the interview session. A copy of the transcript will be provided to you in either hard copy or electronic form (as per your preference), for your review. You will be invited to make additions and deletions to the transcript and return your comments to me. Drafts of the thesis can also be provided to you for review and comment.

Given the nature of the study, I anticipate only minimal potential of risk to participants. Before providing written consent, however, you should be aware that you have the right to withdraw any of your comments or withdraw completely from this study at any time, and that any disclosures or data you provide are held in complete confidence. To preserve confidentiality, pseudonyms will be used in all notes, transcripts, and reports associated with the study. An explicit assurance of confidentiality will be given prior to the interview session. In the final report, all quotations, citations, or paraphrases will be made generic with respect to unique personal features or identifiers, including but not limited to your gender, age, ethnicity, and exact position in the organization. You will be consulted on all excerpts and quotations used in the final writing. All data collected in the course of the study will be held at my home. Transcripts of our audiotaped interview will be shared only with yourself. At the completion of the study, all audiotapes will be destroyed. I anticipate completing this study in summer, 2003. Interview transcripts will be kept in a secure location at my home until any articles arising out the research have been accepted for publication; this period will not exceed five years, after which all interview transcripts will be destroyed. I should also let you know that no compensation is being offered for your participation.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. I can be contacted as follows:

Marcia Friesen
Tel (home)
(city, province, postal code)
Email

My thesis supervisor can be contacted as follows:

K. Lynn Taylor, Ph.D.
Room 220 Sinnott Bldg.
University of (xxx)
Tel (xxx-xxxx)
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Tel (xxx-xxxx)
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Sincerely,

Marcia Friesen, P.Eng.
M.Ed. Student

Please sign below to indicate your informed written consent to participate in this study:

____
Participant's signature Date

____
Researcher and/or Delegate's Signature Date

Letter to Industrial Cooperators of the Design Trilogy

Project Title:	A Qualitative Analysis of Engineering Design Education in the Department of Biosystems Engineering, University of (xxx)
Researcher:	Marcia Friesen, B.Sc. (Agricultural Engineering), P.Eng., M.Ed. student
Sponsor:	None. This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies).

[Date]

[Participant's Name]
[Participant's Address]

Dear [Participant's Name]:

Thank you for considering participation in this research study, as expressed in your recent communication with Dr. (xxx) from Biosystems Engineering, and our subsequent [phone / email] communication. This letter is provided to you to outline the purpose and nature of the study, to formally request your participation in the study, and to obtain your written informed consent as a participant.

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

This research is being conducted as part of a master's thesis in Education (Post-Secondary Studies). A brief introduction of myself as the researcher in this project: I am a 1995 graduate of Agricultural Engineering at the University of (xxx). I spent 1995 – 2000 as a design engineer in engineering consulting in the areas of environment, agriculture and agri-business, and completed the requirements for professional engineering registration. In 2000, I returned to the university to pursue a long-standing interest in graduate studies in education. My goal continues to be to find applications for my graduate work in the Faculty of Engineering. This thesis project, focussed on the Design Trilogy in Biosystems Engineering, is one such application. In addition to graduate work, I have had opportunities to teach sessionally in the Faculty of Engineering, and also have been employed as a program assistant in the Design Engineering department.

The following is a brief context for this research. Nationally and internationally, undergraduate engineering programs have been criticized for the perceived lack of design skills and design competencies of engineering graduates. The University of (xxx) (U of (x)), like other universities in Canada and U.S., has taken these criticisms seriously and has implemented a number of new initiatives to enhance and improve design education for engineering undergraduates. Such new initiatives include the NSERC Design Chair, the Design Engineering department, the Engineer-in-Residence program, and curriculum modifications to introduce design into the first year. The Design Trilogy in Biosystems Engineering is a longer-standing initiative, which is now being viewed with renewed interest. The potential exists to transplant this model of a design course trilogy into other departments within the Faculty of Engineering.

I am interested in exploring how engineering design education is conceptualized within the Design Trilogy in Biosystems Engineering (course numbers 34.258, 34.358, and 34.458 (formerly 34.214, 34.326, and 34.413, respectively)) here at the U of (x). Specifically, my purpose in this study is to understand participants' conceptualizations of teaching and learning in engineering design education. The objectives of the study are to (1) understand design participants' views, opinions, ideas, and perceptions of design and engineering design education in the Design Trilogy; and (2) to understand how these perceptions guide your role as an industrial co-operator in the Design Trilogy. To fulfill these objectives, I am recruiting the three Design Trilogy instructors, the NSERC Chairholder, and six industrial co-operators of the Design trilogy for one-on-one interviews, and recruiting students of the three Design Trilogy courses for focus group interviews.

Should you agree to participate, you and I will engage in one face-to-face interview of approximately one-half hour duration. The interview will be scheduled for December 2002 or January 2003, after the Design Trilogy courses are complete for the 2002-2003 academic year. The interviews will be held at a time and location suitable for you. The interview strategy will follow qualitative interviewing norms; as opposed to a structured question and answer session, the format will be conversational and relaxed. I will make reference to a prepared interview guide with open-ended questions to guide our conversation. My role in the interview will be to provide an atmosphere in which you feel comfortable disclosing your feelings, perceptions, and opinions relative to design and engineering design education.

Consistent with qualitative interviewing norms, I will audiotape the interview and transcribe the audiotape immediately after the interview (within 24 hours). The transcript will also include notes about non-verbal features of the situation (such as location, atmosphere, tone, body language) taken from my written notes during the interview session. A copy of the transcript will be provided to you in either hard copy or electronic form (as per your preference), for your review. You will be invited to make additions and deletions to the transcript and return your comments to me. Should you desire, drafts of the thesis can also be provided to you for review and comment.

Given the nature of the study, I anticipate only minimal potential of risk to participants. Before providing written consent, however, you should be aware that you have the right to withdraw any of your comments or withdraw completely from this study at any time, and that any disclosures or data you provide are held in complete confidence. To preserve confidentiality, pseudonyms will be used in all notes, transcripts, and reports associated with the study. An explicit assurance of confidentiality will be given prior to the interview session. In the final report, all quotations, citations, or paraphrases will be made generic with respect to unique personal features or identifiers, including but not limited to your gender, age, ethnicity, and exact position in the organization. All data collected in the course of the study will be held at my home. Transcripts of our audiotaped interview will be shared only with yourself. At the completion of the study, all audiotapes will be destroyed. I anticipate completing this study in summer, 2003. Interview transcripts will be kept in a secure location at my home until any articles arising out the research have been accepted for publication; this period will not exceed five years, after which all interview transcripts will be destroyed. I should also let you know that no compensation is being offered for your participation.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researcher, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and/or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation. I can be contacted as follows:

Marcia Friesen

(city, province, postal code)

Tel (home)
Email

My thesis supervisor can be contacted as follows:

K. Lynn Taylor, Ph.D.
Room 220 Sinnott Bldg.
University of (xxx)

Tel (xxx-xxxx)
Fax (xxx-xxxx)
Email (xxx@xxx.ca)

Other committee members are:

M.G. (Ron) Britton, P.Eng., Ph.D.
Rm. 107 Engineering Bldg.
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Tel (xxx-xxxx)
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Email (xxx@xxx.ca)

David Kirby, Ph.D.
Room 220 Sinnott Bldg.
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Email (xxx@xxx.ca)

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project, you may contact the above-named persons or the Human Ethics Secretariat at 474-7122. A copy of this consent form has been given to you to keep for your records.

Sincerely,

Marcia Friesen, P.Eng.
M.Ed. Student

Please sign below to indicate your informed written consent to participate in this study:

____

Participant's signature Date

____

Researcher and/or Delegate's Signature Date

Appendix C
Interview Guides

Guide 1: Interview Guide for DT Instructors and NSERC Design Chairholder:

The following passage will be read at the beginning of each interview session:

> Thank you for agreeing to participate in this study. I am interested in exploring your concepts or understandings of engineering design and engineering design education, and how these concepts shape your own role in planning and delivering engineering design education. The questions have been designed to explore these areas. This interview is designed to follow qualitative norms, which may be different from quantitative inquiry norms to which you are accustomed. The goal is to see our time together as a relaxed conversation and not a structured question-and-answer period. You are free to withdraw from this study at any time and you are under no obligation to answer any of the questions. When I transcribe the audiotape and report the results of the study, I will use pseudonyms and will not use any quotations that would identify you specifically. Everything you say will be held in confidence. After I have transcribed the audiotape, the transcript will be returned to you for your review. No one except myself will have access to the data and the audiotape will be destroyed when the transcript is complete. Do you have any questions about these procedures?

The following questions and probes will guide the interview:

- Tell me something about yourself.
  - What has your professional career path been?
  - What role has design played in your career?
  - What experiences preceded your role in the [DT] [NSERC Chair]?

- How do you define design?
  - What are key components of a definition of design?
  - Who or what has guided or shaped your definition of design?

- What are your approaches to or philosophies about teaching design?
  - Who or what has guided or shaped your approaches or philosophies of teaching design?
  - How does your understanding of design relate to your understanding of design education?

- How do you conceptualize teaching design?
  - What role do learning theories play for you, to support learning design?
  - What are the learning goals you set out for your course?
  - What teaching strategies do you use?
  - What do you consider the most important pedagogical considerations in teaching design?
  - Are there themes to which you give conscious deliberation in your teaching of design?
  - What are your thoughts on such themes as a 'cornerstone' paradigm, collaborative teamwork, industry collaboration, interdisciplinary focus, oral/written communication, lecture content, and leadership experiences for students?
  - How do you prioritize these dimensions?
  - How do you accommodate these dimensions?

- How do you conceptualize assessment and evaluation of learning in design courses?
  - What strategies do you consider appropriate?
  - How do you plan to assess and evaluate learning in your course?
  - How do these strategies compare to those used in other courses?
  - What learning outcomes do you identify in the students, as a result of the DT?

- How do you conceptualize your role as [a faculty member in the DT courses][as the NSERC chairholder]?
    - Describe your primary role.
    - In what ways do you collaborate with [other DT instructors] [other design faculty]?
    - Describe your idea of course synergy.
    - How could each course be improved?
    - How could connections across courses be improved?

Guide 2: Interview Guide for DT Students:

The following passage will be read at the beginning of each interview session:

> Thank you for agreeing to participate in this study. I am interested in exploring your concepts or understandings of engineering design and the design trilogy in Biosystems Engineering. You are currently enrolled in one of these three courses. The questions have been planned to explore these areas. This interview is designed to follow qualitative norms. In qualitative interviewing, the goal is to see our time together as a relaxed conversation and not a structured question-and-answer period. You are free to withdraw from this study at any time and you are under no obligation to answer any of the questions. My assistant will be taking notes as we talk and the data analysis will be based on those notes. When I analyze the notes and report the results of the study, I will use pseudonyms and will not use any quotations that would identify you specifically. Everything you say will be held in confidence. In addition to the notes, I am audio taping this focus group session as a back-up only. No one except myself will have access to the data, and the audiotape will be destroyed when the study is complete. Do you have any questions about these procedures?

The following questions and probes will guide the interview:

- Tell me something about yourself.
  - What do you currently identify as your key roles?
  - What are the most important things about you right now?
- How do you define design?
  - What are key components of a definition of design?
  - Who or what has guided or shaped your definition of design?
  - How do you anticipate using design in your careers?
- How do you experience learning design in the design trilogy course[s]?
  - What are the learning goals of the DT, as you perceive them?
  - What personal learning goals do you have for this course?
  - What features of the course (e.g. teaching strategies, content, learning experiences, etc.) seen individually and as a trilogy, do you identify as facilitating achievement of these learning goals?
  - Do you perceive 'teaching' in the DT to be different from 'teaching' in other courses?
  - If so, in what ways?
  - What teaching strategies do you identify as being unique to the DT?
  - What teaching strategies do you identify as being particularly useful or supportive to learning design?
  - Do you perceive the course to emphasize any of the following: design projects, collaborative teamwork, industry collaboration, interdisciplinary /multidisciplinary focus, oral/written communication, lecture content, and leadership experiences.
  - To what extent does engagement in these themes help or hinder learning?

- How do you describe the role of the faculty member in the DT?
    - What do you identify as important role(s) for a design professor?
    - In what ways are the role(s) of a design professor different than professors in other courses?

- What learning outcomes do you identify in yourselves as a result of the design trilogy course[s]?
    - What are the most important or useful things you learn in the DT course[s]?
    - To what extent do you identify a progression of learning within yourselves as you move through the DT?
    - How does the structure of the DT affect this progression?

- To what extent do you perceive collaboration and synergy between the three courses in the DT?
    - How could each course be improved?
    - How could the connections between courses be improved?

<u>Guide 3: Interview Guide for Industry Cooperators:</u>

The following passage will be read at the beginning of each interview session:

> Thank you for agreeing to participate in this study. I am interested in exploring your concepts or understandings of engineering design and engineering design education, and how these concepts shape your own role as an industrial client in the design trilogy in Biosystems Engineering at the U of M. The questions have been planned to explore these areas. This interview is designed to follow qualitative norms, which may be different from quantitative inquiry norms to which you are accustomed. In qualitative interviewing, the goal is to see our time together as a relaxed conversation and not a structured question-and-answer period. You are free to withdraw from this study at any time and you are under no obligation to answer any of the questions. When I transcribe the audiotape and report the results of the study, I will use pseudonyms and will not use any quotations that would identify you specifically. Everything you say will be held in confidence. After I have transcribed the audiotape, the transcript will be returned to you for your review. No one except myself will have access to the data and the audiotape will be destroyed when the transcript is complete. Do you have any questions about these procedures?

The following questions and probes will guide the interview:

- Tell me something about yourself.
  - What has your professional career path been?
  - What role has design played in your career?
- How do you define design?
  - What are key components of [a definition of] design?
  - Who or what has guided or shaped your definition of design?
- How do you understand your involvement in the DT as a client?
  - What motivated you to become involved in the DT as a client?
  - What are your most important needs in terms of design?
  - In what ways does the DT support these needs?
  - What do you hope to accomplish by being involved in the DT as a client?
- What are your expectations for the DT courses?
  - What design skills do you consider necessary for graduating engineers?
  - What are your expectations of the students in the design course?
  - What are your expectations of the faculty of the DT?
  - How do the courses meet these expectations?
  - How do the courses fall short of these expectations?
  - How do you measure success of a design course?
  - How do you measure success of a design project?
- How do you evaluate the DT courses?
  - How did the projects develop design skills?
  - What strengths do you perceive of the courses in their current form?
  - What recommendations do you have for improving design education generally?
  - What recommendations do you have for improving specific courses in the DT?

Appendix D
Samples of Coded Data

[redacted]: Well, some of it is, "can you play well in the sandbox?", so it's a group issue. Although I think in this department that's less of an issue, by and large, as compared to say when I was in City Planning or in the Civil department. I mean, I think we do a reasonably good job in Biosystems of that.

Culture

MF: So the goal is developing team skills?

Goal #2

[redacted]: Yeah, I think, I would think there's team skills and seeing how people perform with each other and how they manage their time. There's also a time management issue. And I guess from more the hard skills side of it is a case of up front, trying to evaluate how long you think it might take to do this particular project and then being able to reflect on that at the end of the term. So there's some very real, you know, concrete – they are quantifiable in that sense – we based our – and I think we discussed it last time – but right up front they have to give me a proposal in terms of what they're going to charge to do this project and how many hours they think are involved. Before we've even had a discussion of "what are you worth". So I'd rather have them do that thinking up front, so that they've got to confront these issues without any kind of information except what they themselves bring from their own work experience or whatever. And then at the end of the term, hopefully to be able to stand back a little bit, although I don't

Goal #3

Assignment Content Strategy

Need follow-up

Theme	(Participant name)	(Participant name)	(Participant name)	(Participant name)
Design Constraints	Time p.13	Time p.16	Timing p.24	Time p.28; 36
	Ability p.13		Abilities p.25	Own comfort level p.29; 32; 36
	Understanding p.13			
	Consequences of error p.13			
	Safety p.14, 15			Code constraints p.30
	Resources p.15			Equipment. p.5
	Economics p.15	Cost p.11; 12	Financial p.25	Economics + Marketing p29; 30
		Consistency w/ some other product p.11		Material restrictions p29
		Consistency w/ cultural norms p.11		Cultural context + norms p.14-15; 29; 31
		Acceptable to client + larger society p11; 13	Clients vision, needs p.26	Clients views p.30
			Human constraints p26; 27	Ethical considerations p.33

Appendix E
Education/Nursing Research Ethics Board Approval Certificate

APPROVAL CERTIFICATE

16 May 2002

TO: **Marcia Friesen** (Advisor L. Taylor)
Principal Investigator

FROM: **Lorna Guse, Chair**
Education/Nursing Research Ethics Board (ENREB)

Re: **Protocol #E2002:036**
"A Qualitative Analysis of Engineering Design Education in the Department of Biosystems Engineering, University of [redacted]

Please be advised that your above-referenced protocol has received human ethics approval by the **Education/Nursing Research Ethics Board**, which is organized and operates according to the Tri-Council Policy Statement. This approval is valid for one year only.

Any significant changes of the protocol and/or informed consent form should be reported to the Human Ethics Secretariat in advance of implementation of such changes.