Understanding and Improving Undergraduate Engineering Education

by

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A thesis
presented to the University of Waterloo
in fulfilment of the
thesis requirement for the degree of
Master of Applied Science
in
Systems Design Engineering

Waterloo, Ontario, Canada, 2001

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

This thesis seeks to understand the past and present state of engineering education and to plot a course for its future evolution. This research is limited to engineering education as it has taken place in North American universities during the last half of the 20^{th} century. Within this context, broad trends are described. The description is supplemented with a case study of a unique and innovative engineering programme. The trends and case study form the foundation of a synthesis, and alternative vision, for higher education and engineering education. The intended audience of this thesis includes those who teach, design curriculum, or administer engineering education programmes.

The description of the current state of engineering education contains analyses of the state and of the gaps within it. Both of these analyses are based almost exclusively on publicly available documentation. The present state of engineering is drawn from accreditation criteria. Critiques of the current state and suggestions for future change are drawn from reports commissioned by groups affiliated with professional engineering. The discussions identify recurring themes and patterns. Unlike the analysis of the literature, the case study merges interview evidence and personal experience with the available documentation. The synthesis and visions continue the trend away from formal sources towards experiences and beliefs.

Engineering education research is in its infancy and shows few signs of maturing. There is no documented, common framing of engineering education nor have there been any efforts in this regard. Few sources address broad issues and those that do lack theoretical rigour. The visions for engineering education are simple amalgams of visions for the profession and for general higher education.

The Department of Systems Design Engineering has enjoyed great past successes because of its unique vision that combines the theories of systems, complexity, and design with the discipline of engineering. Its recent decay can be traced to its faculty having collectively lost this vision. The original vision for Systems Design Engineering holds promise as a means to reinvent and reinvigorate both the engineering profession and engineering education. For this renaissance to be successful a theoretically rigorous research programme assessing the past, present, and future of engineering and engineering education must be developed.

Acknowledgements

Peter R. who let me try something a little different

James K. for showing that engineering is not only complicated but actually complex

Glenn H. for showing that optimism can survive cactus-like in the midst of a desert of cynicism

Kate H. who suffered through one degree, two incompletes, three years, and a week of editing and yet didn't commit homicide

Kristine M. who makes people go

Roydon F. for inflicting me on a captive audience

Beth J. for interpreting "kick in the pants" literally

Donna E. who made sure I didn't lynch and of my students, and vice-versa

Wayne L. who let me interrupt his coffee

Beth D. and Eric T. who are very confusing

The Hoyes who tolerated a single-minded freeloader

The Gang who never stopped asking "Is it done yet?"

The SYDE class of 2002 who also never stopped asking "Is it done yet?"

Bruno and Boots who provided hours of entertainment and diversion in exchange for a few cat treats

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Chapter 1

Introduction

Engineering education is a subject of crucial importance that has been largely neglected. The US Commission on National Security/21st Century made it clear that the importance of science and engineering to the future prosperity of nations cannot be overstated.

> "In this Commissions view, the inadequacies of our systems of research and education pose a greater threat to U.S. national security over the next quarter century than any potential conventional war that we might imagine. American national leadership must understand these deficiencies as threats to national security. If we do not invest heavily and wisely in rebuilding these two core strengths, America will be incapable of maintaining its global position long into the 21st century.
>
> We also recommend a new National Security Science and Technology Education Act to fund a comprehensive program to produce the needed numbers of science and engineering professionals as well as qualified teachers in science and math." [258]

Even though its economic and social importance has been recognized engineering education is just beginning to be treated as a legitimate topic of study. Past efforts have been hampered by the interdisciplinary nature of the subject. The study of discipline-specific approaches to teaching and learning does not fall under the mandate of either the natural science or the social science funding bodies. It is curious that the engineering profession and associated funding bodies have not supported engineering education research given that educating engineers has been defined as an act of professional engineering.

The engineers acts of Alberta, Newfoundland, and the Yukon Territory, as well as the Model Law developed by the United States National Council of Engineering Examiners, all make explicit reference to the teaching of either advanced engineering subjects or engineering design as being part of the practice of professional engineering. [204, 205, 280, 180] The definitions of engineering in the acts of other Canadian jurisdictions are sufficiently broad that a case in favour of the teaching of engineering can be made. The accreditation guidelines from the Canadian Engineering Accreditation Board (CEAB) also link aspects of engineering education to the engineering profession.

> **2.3.5** Faculty teaching courses which are primarily engineering science and engineering design are expected to be registered professional engineers in Canada.
>
> **2.3.7** It is expected that a majority of the member of such a body [responsible for initiating changes in the curriculum] be registered professional engineers in Canada. [32]

If only professional engineers can practice engineering, and in general only professional engineers should teach engineering[1], then teaching engineering is part of the practice of engineering. In spite of this, Natural Sciences and Engineering Research Council of Canada (NSERC), which is the largest engineering research funding agency in Canada, has only recently begun to incorporate education into their funding initiatives.

> "[The Canadian Design Engineering Network] will address design engineering education and research, promote the sharing of design resources and the awareness of design in partnership with industry, and serve to foster design engineering innovation across engineering disciplines." [192]

NSERC may include education as part of the responsibilities of selected chairs and groups, but it still does not have a funding group devoted to this topic. The Social Science and

[1] See section 6.11.

Humanities Research Council (SSHRC), is the other major funding group that supports research in areas related to engineering education but it is also unwilling to commit funds to investigate engineering education.

Fortunately, new opportunities for funding are developing. Very recently a corporation university donation was earmarked for the creation of a research chair in engineering education.

> "At a ceremony today [October 14, 2000], Queen's University announced the founding of the DuPont Chair in Engineering Education, Research and Development in the Faculty of Applied Science thanks to a major gift of $ 2.5 million from DuPont Canada Inc. 'Over the next 100 years, creating superior human capital will make a critical competitive difference among countries and regions,' says [Principal Dr. William C.] Leggett.'This generous gift from DuPont Canada places Queen's in a strong position within the competitive environment of 21st century engineering education'." [206]

These initiatives are positive steps towards the recognition of this previously neglected and yet highly important research area.

1.1 Research objectives

This research seeks to make a contribution to this emerging field. The primary objective is to set the stage for future work in improving engineering education. A very comprehensive review of the literature is compiled so that the current state of engineering education and, in particular, any weaknesses within the current system can be described. To prepare for future research a number of conceptual models are developed to frame this discussion of the engineering education sources. The review is presented in chapter 3 and chapter 4. The literature review is supplemented by a case history of an innovative engineering department. This case history is presented in chapter 5. Chapter 6 presents a vision of engineering and engineering education based on the work presented and a synthesis of relevant literature and experience.

1.2 Scope

This research is limited in scope to the events between the end of the second world war and the present. The period of time between the end of the war to the mid 1960's was a time of both immense growth and immense change in North American engineering education. During this time civil[2] engineering education changed from a model based on apprenticeship and experience to one based on formal education and scientific analysis. Since the 1960's there have been changes in the tools used in engineering education. For example, the development of analytic and symbolic solvers and Computer Assisted Design tools has had a large impact on how selected engineering material is delivered. However, the shape and context of engineering education has remained fundamentally unchanged during this period. [179]

This research focuses on engineering education within the Canadian context. Unfortunately the scope of Canadian activities and research into Engineering Education is significantly smaller than that of the United States. Accordingly, where appropriate, American sources will be used.

This research deals primarily with university or college-level education. Education can, and I believe must, be treated as a continuous process that takes place at all ages and in all locales. However, in the time period covered in this research, the majority of formal engineering education has taken place at the undergraduate level when the students are in their the late teens and early twenties.

There is a wide variety of technical programmes ranging from undergraduate honours degree programmes to college certificate courses. This thesis will describe only those programmes that are recognized by the engineering accreditation boards. In Canada, this restriction limits the investigation to programmes within university faculties of engineering.

[2]'Civil' meaning "not military" as opposed to "concerned with structures".

Chapter 2

Reflexion and Context

This chapter is about this thesis, about me, its author, and about the world I see around me. Even though academic works often include a brief biographical sketch of the author, devoting an entire chapter to these topics is quite unusual. Accordingly this chapter accomplishes two things. First, it justifies its own existence. Second, it describes the world into which this thesis fits.

2.1 A definition of and a rationale for reflexion

re·flex·ive *adj.* denoting an action by the subject upon itself [38]

A reflexive approach to a thesis requires that the thesis, its author, and their respective contexts be addressed as subjects of discussion and analysis. Context refers to the amalgam of conditions or circumstances affecting the author and the thesis, including assumptions and personal background. A traditional approach to a thesis allows for some discussion of the thesis and its context. This description has been provided in the introductory chapter and will not be repeated. In contrast to the traditional approach, reflexion is predicated on the belief that that the work and the author are inextricably intertwined. Therefore, this chapter presents the author's context as it relates to this thesis.

The value of reflexive practice has been recognized in education, cybernetics, and engineering, three areas that are relevant to this thesis. The literature on education now commonly includes references to “learning how to learn”. Cybernetics has introduced the notion of second order cybernetics which is defined as the “cybernetics of systems involving their observers as opposed to the cybernetics of systems that are observed from the outside”. [118] Krippendorff added that second order cybernetics “involves the observer as a constitutive part of a circular organization and is concerned with self-reference, epistemology, autonomy, self-government, autopoiesis to name just a few phenomena”. [162]

Those who would practice reflexion must always guard against it degenerating into recursion.

> “When I began to write this sentence I perceived the world in a certain way. Writing this sentence has changed how I perceive the world. I now perceive the world in a different way. But again writing this sentence has changed how I perceive the world...”

The only way out of this cycle is to decide, based on experience and the nature of the circumstances in question, that sufficient reflexive iterations have been performed.

Similarly, reflexion can become an endless task unless an arbitrary boundary is set separating those aspects of the subject and context that will be considered from those that will not be considered. Flood and Carson propose two sets of heuristics to guide boundary setting. [113] While they do provide some guidance, in the end like all heuristics they rely on the judgement of the researcher.

Within the engineering community reflexion and context have been discussed by a number of authors. Florman's *The Introspective Engineer* and *The Existential Pleasures of Engineering* address these topics from the perspective of engineering ethics. [117, 116] Petroski addresses reflexion and context from the perspective of engineering education. *Remaking the World* includes a chapter, titled “In Context”, devoted exclusively to these issues. [202] In this chapter Petroski calls for the inclusion of context and reflexion in engineering education. He identifies historians of technology as those researchers most equipped to introduce these topics to engineering students.

2.1.1 The methodological uses of reflexion and context

Reflexion can be described as an exploration of the context of a research endeavour. A number of problem solving methodologies in engineering and social systems also advocate an exploration of the context of a situation.

A well known methodology for dealing with social systems is part of Checkland's Soft Systems Methodology. [113, 43] Perhaps the most widely adopted piece of the SSM is the Rich Picture method. The Rich Picture method is a tool that is used by multiple participants to develop a shared understanding of a situation. The resulting Rich Picture defines the context into which any intervention must fit.

An engineering design process also deals explicitly with the problem of defining context. The design process starts with the identification of a perceived defect and a needs analysis. "The purposes of Need Analysis are to establish the scope, objectives, and background of the design project." [210, page 141]

Engineers, especially those who can leverage existing codes or examples, must deal explicitly with issues of context. For example building codes are tailored for particular contexts. In this case the context includes factors such as temperature, the depth of frost, and humidity. A structure that meets the code in one context may be totally unsuitable in another context. The engineer is responsible for validating that the contexts are sufficiently similar that the code requirements can be transplanted without modification.

2.1.2 The personal requirements for reflexion and context

I am interested in both *what* an author believes and *why* he or she believes it. I was motivated to include this chapter because of my dissatisfaction with almost all of the scholarly papers I have read. My interests lie in areas that are primarily qualitative in nature and as such require interpretation and opinion on the part of the researcher. Very rarely do authors say explicitly "this is opinion" or "I have faith that this is correct". Instead the simply authors tend to proceed with their papers leaving the reader to wonder why a particular interpretation was made or path followed.

As mentioned in section 2.1.1 I believe that the notion of context is an important part of engineering. In section 6.12 I present an alternative vision of engineering centred around ethics, reflexive awareness, judgement, and the awareness of context. Accordingly I believe that all engineers should practice these skills. In more quantitative papers there may be less need for reflexive content. However even the most quantitative result in engineering is embedded within a context and contains assumptions.

As a current engineering student, and prospective engineering professor, I have a major concern with much engineering content. Textbooks and lectures, at least at the undergraduate level, present much of their material, more or less, as a seamless whole. Students are not told of the false starts, dead end avenues, and frustration that went into developing the material. The teaching materials also tend to include minimal contextual information. For example in a 2^{nd} year dynamics course students are told that :

$$F = m \cdot a \tag{2.1}$$

although there is the proviso, provided in a footnote, that:

> Stated another way, the unbalanced force acting on the particle is proportional to the time rate of change of the particle's linear momentum. [139]

A more general definition accounts for relativistic effects[1]:

$$F = \frac{dp}{dt} \tag{2.2}$$

where

$$p = \gamma \cdot m \cdot v \tag{2.3}$$

and

$$\gamma = \frac{1}{\sqrt{1 - (v^2/c^2)}} \tag{2.4}$$

Undergraduates are unlikely to need this information so the provision of it could appear to be an academic indulgence. However relativistic effects do come into play in modern engineering, for example in the calculations used by the Global Positioning System. An engineering student unaware of the context of equation 2.1 may use it inappropriately.

[1] This more general definition is also the original definition proposed by Newton. Accordingly Einstein's work enhanced, not contradicted or superseded, that of Newton.

Accordingly I believe that it is the responsibility of engineering professors and teaching materials to make their context explicit.

I believe that including context and reflexive content may promote a more reflexive attitude in the reader. When I come across an unsupported contentious position I tend to react in a visceral way. Conversely I am more likely to be reflexive when the position includes more supporting material. Including such material in my own work serves my goal of promoting reflexive activities in the engineers and educators who I expect to be my readers.

2.2 Personal reflexion and context

This section presents the reflexion and context that was called for in section 2.1.1. My goal for this section is to introduce you, the reader, to the world I saw around me while I was developing this thesis.

As an undergraduate engineering student I engaged in what I would consider typical student whining. Much of the whining, recast as criticisms, is documented in section 5.1. My research is an attempt to move beyond unconstructive criticism, to offer some constructive suggestions.

My high school education was at a private liberal arts institution. Admission to the school was based primarily on academic considerations. As a rule graduates of this institution did not pursue higher education in disciplines such as science or engineering. From a graduating class of approximately 150 perhaps 5 students enrolled in these fields[2]. Science and engineering was, stereotypically, seen by the students as a less interesting and more menial career path.

My undergraduate education was in Systems Design Engineering (SYDE) at the University of Waterloo. Admission to this programme and institution were also based on academic considerations. As will be discussed in section 5.1, this programme was designed to produce individuals who could be described as "liberal engineers".

Three key concerns come from my academic background. First my academic colleagues

[2]This number is based on my impressions of my graduating class. The institution keeps records only of the institutions attended by its graduates.

have always been incredibly able within their context. In my mind all students are capable of accomplishments equal to those in my experience. This may not in fact be the case. The second concern is that the curricula I have been exposed to were designed for a minority. These institutions chose to push bright students to be skilled in as broad a capacity as possible. Based on my experiences I tend to prefer breadth and abstraction over depth and concreteness. The third concern is that I tend not to value the construction of physical artefacts. Neither the curriculum of my high school nor of Systems Design Engineering included significant hands-on experiences.

> "One must learn by doing the thing, for though you think you know it, you have no certainty until you try." – Sophocles

While I agree with Sophocles' position I believe that knowing a thing (the *what*) and the act of doing a thing (the *how*) are not sufficient for learning. It also requires knowing the *why*. This belief has been influenced by a number of anecdotes. The most telling involves the American space programme. I have heard anecdotally that the United States has lost most of the knowledge required to put a person on the moon. The lost knowledge is in the form of manufacturing equipment, manuals, and in the minds of individuals who have left or passed away. What has not been lost are examples of the actual devices required to complete the task. In theory these devices could be reverse-engineered and the moon programme recreated. My opinion is that reverse engineering would be insufficient. Reverse engineering tells you that a valve with certain operating characteristics should be in a particular location. It does not tell you why that is the case. Henry Petroski (see section 6.9.1) believes that failure plays a vital role in successful design and engineering. [199] Reverse engineering a successful design tells you nothing about the failures that led to the success.

My preferred learning style also biases my perceptions on education. My technique for succeeding in school[3] was based on two approaches. The first approach was to deriving from underlying principles[4]. My belief is that an individual who is comfortable learning about

[3] In my opinion success in school does not require learning. I successfully passed many courses where I feel I did not, and continue not to understand the content. In some cases I may know the *how* or *what* of the material, but I am still uncertain as to the *why*.

[4] An underlying principle is distinct from a first principle. A first principle is an absolute. An underlying

underlying principles and skilled at derivation is more effective than someone who knows the results of the derivations. A side benefit of a problem solving technique that incorporates derivation is that it promotes a continual awareness of context. My second approach to academic success involved developing an understanding of my professors' expectations. Older students, past exams, course outlines, and, in rare cases, the professor's own academic works served to inform my understanding. Sometimes a professor would be willing to participate in a dialogue on the course and their expectations. Once I had developed some understanding, I could approach the course in one of two ways. The first, safer way was to strive to fulfil the professor's expectations. The second, riskier approach was to challenge those expectations. In either case, the ability to discover my professors's expectations was essential.

After finishing my undergraduate degree I worked in the software industry for a year. My experiences in this industry, both during cooperative education experiences and after graduation, have exerted a tremendous influence on my views regarding engineering and education. Two different aspects deserve mention.

First, software differs from other more tangible deliverables in a number of important ways. The first is that there is a low impedance between design and implementation. Given a few fundamental assumptions, namely that a Turing machine is involved, going from a design to an implementation is a very simple process. Put another way the "model" of software is very similar to the "reality".

Second, my experience taught me the value of deep understanding of the philosophies that guide tool development and practice in a field of endeavour. While many people believe that the field of information technology grows and changes rapidly, I believe that this is only true at the level of implementation details. The number of languages and programming methodologies is growing quickly. The number of different ways of thinking about programming is growing at a much slower rate. Unfortunately many contemporary programming courses and books focus on the syntax of a single programming language and give little attention to general concepts. It is interesting to note that the more "classical" references described the mental models that went into the design of particular languages or the solution of particular problems. [227, 85, 264]

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principle is one that exists somewhere between the first principles and the end results.

My industry experience involved multiple computer languages and I worked with colleagues with a variety of educational backgrounds. My colleagues exhibited vastly different abilities to apply insights from one language to another. Those programmers who had been trained by the colleges to solve a particular type of problem in a particular language were extremely efficient within that context and could develop solutions with little or no ramp-up time. When the context changed they were lost. Those with more education tended to see programming as a way of thinking. They might start out lost but they were always able to find their bearing quickly.

The deep understanding of software tools and methodologies was also supported by my experiences with software consulting projects. A key characteristic of the software industry is that requests for customization are endless. In my experience it has been common for the client to call management two or three times a day to request new or changed features. The ability of programmers to adapt to these requests also seemed to be related to how abstractly they approach problems.

Based on these observations I believe that students should be taught generalities, concepts, and modes of thought. Learning details and specifics is the responsibility of students as they progress through their lives and careers. I am not claiming that details and specifics are less important than generalities. My claim is that the limited time available to educators would be better spent teaching people to see trends and the big picture. This perspective does have a few problems. I was only able to see the general trends after having programmed on and off for eight years. Some programmers in my experience have been programming for years and do not share my beliefs. My supposition is that individual learning styles and preferences play a major role in how people perceive programming. In this I am torn because I firmly believe that individuals who cannot see underlying patterns will be unable to survive, over the long term, in the complex world that seems to be emerging[5]. For some, learning to see patterns is extremely difficult. However I also believe in equal access to opportunity, which a focus on underlying patterns may not allow. It

[5]I acknowledge that there are those individuals who excel at finding, and filling, niches within larger systems. Surviving within these niches may involve neither seeing the "big picture" nor underlying patterns. My opinion is that if such individuals are able to find new niches as their environment changes then, at some level, they are aware of the patterns that surround them. They have simply chosen to leverage this awareness on a more infrequent basis.

seems clear that I will have to rectify these beliefs.

One final observation concerns the effectiveness of traditional models of education. A study done at Harvard in the early 1980s revealed that graduating students and faculty members continued to believe in incorrect explanations of common phenomena. [217] In spite of learning significantly more sophisticated explanations of the phenomena, the participants appeared to cling to the simplistic explanations they learned early in life. I have noticed that, under duress, I will think in terms of the first programming language I was taught even though its applicability to contemporary problems is limited. I am not about to argue that we should teach quantum mechanics in grade school. However I do believe that the science and art of education must focus on how these fundamental beliefs can be enhanced, adjusted, or replaced.

Chapter 3

What was and what is the state of engineering education

This chapter begins with a brief survey of the history of engineering education in North America. The survey is followed by an attempt to draw together a comprehensive description of the current state of engineering education. This discussion is based on discussion papers, articles published in the engineering education journals and the documents published by the engineering accreditation organizations.

3.1 The history of engineering education

This history has been distilled in large part from *The Other Re-engineering of Engineering Education* and *The Evolution of Engineering Education in Canada*. [219, 179] The basic distillation has been supplemented with information drawn from a number of less focused, ancillary sources. [48, for example]

The history of engineering education in North America can be divided into three eras[1]. The first is pre-1920. During this era the dominant model of engineering education was apprenticeship. In the late 1800s engineering students learned their trade as apprentices in established engineering shops. By definition engineering "graduates" had the exact set

[1]As discussed in section 1.2, this thesis is primarily concerned with civil engineering eduction in North America after the second world war. Military engineering education is excluded from this discussion.

of skills needed by industry. In the early 1900s engineering education began to move into colleges. The approach taken was in essence to create an engineering shop within the college. Students continued to construct devices on a shop floor and to draft plans in a studio. The only substantive difference was location.

In this era, formal training in mathematics and science was generally absent. This is not to imply that mathematics was not an essential component of engineering. The slide rule, invented in 1632, the force polygon, invented in the 1860s, and nomograms, invented at the end of the 19^{th} century, were all mathematical tools widely used by engineers until the advent of widespread computing. [111] During this era engineering training focused on the use of mathematical tools, not on their underlying principles. [111]

The second engineering era took place from 1920-1960. This era, through it lasted roughly 40 years, was mostly transitional. By the 1920s engineering education in Europe had begun to incorporate formal science and mathematics. A visiting French engineer remarked in 1920 that "There is nothing in the United States comparable to the preparation of our École Polytechnique or the École Centrale. The first-year students, the freshman, of the engineering schools, are very weak." [219] European engineers working for American companies began to develop reputations for superior abilities. To address this weakness American educators began to incorporate basic mathematics and science into engineering education. The essential character of engineering education remained hands-on and experiential. The vast majority of engineering graduates continued to be taught as though they were working in an industrial shop and to meet the exact needs of industry. Special programmes, such as engineering physics and engineering science, were developed for those students who wished to delve deeper into the scientific approaches to engineering. These students were generally more able to participate in the fledgling engineering research programmes that were being established.

The contemporary engineering era began after the second world war. This era began with a massive infusion of resources and a new mandate from government. Engineering needed to become more research oriented. Science, mathematics, and theory were to become the basis of the engineering curriculum. New undergraduate programmes and graduate research groups were created. The focus was to be on research and technology in the service of military and economic growth.

3.2 Assessment model

The remainder of this chapter is dedicated to the creation of a comprehensive description of the engineering education in the contemporary era. The significant sources will be evaluated using the assessment model described in this section.

Each of the sources used to describe the current state of engineering education embody a model of engineering education. These models will be assessed using the following variables: scale, type, cohesion, acceptance, substantiation and goal. Each variable is associated with a scale which represents a continuum. All of the scales are relative. The scales are depicted in figure 3.1.

After a document or a set of documents have been assessed, a marker will be placed on each axis to indicate the point on the continuum that best describes the document or documents. A document or set of documents can contain significant variability. Therefore, shaded arrows are used to indicate the variability with respect to each axis. The scale

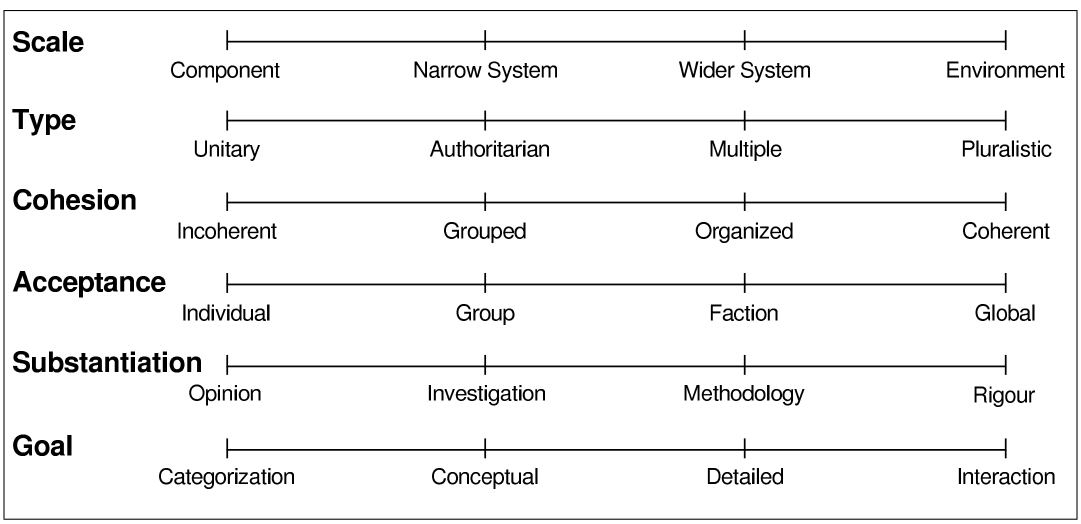

Figure 3.1: A model for assessing engineering education materials

axis is based on the terminology used by Flood and Jackson and describes the number of things considered. [113] Table 3.1 describes and provides examples of the terminology on the scale axis. There is a major limitation to the use of this variable as a descriptive tool.

Measure	Explanation	Example
Component	A single entity that is treated in relative isolation.	Course
Narrow system	A collection of interrelated components that are considered directly relevant and are both observable and controllable. May be referred to as “system of interest”.	Department
Wider system	An expanded collection of components that is a super set of the narrow system. Begins to incorporate components whose relevance is less obvious and that may be neither observable nor controllable.	Faculty
Environment	That which is outside of the wider system but that may shape the evolution of the system. Begins to address issues of co-evolution.	University

Table 3.1: Different types of scale

The same entity may fall in a different location depending on the observer's perspective. For example, a Dean of Engineering may see a department as a component whereas an Instructor may see it as the wider system of interest.

For the purposes of this thesis entities such as industry, the engineering profession, and the research funding community are expected to be contained within the wider system of interest. Given this definition of scope, preference will be given to discussions to take place somewhere between the narrow and wider system of interest. Politics and the social and economic impacts of technology fall into the environment and will be excluded.

The type axis is also based on the work of Jackson. [150] It identifies the number of perspectives represented by the model and how the perspectives are presented. Table 3.2 describes and provides examples of the terminology on the type axis. The systems literature uses the term ‘imperialistic’ instead of ‘authoritarian’. [150] Out of deference to the negative connotations implied by ‘imperialistic’, this thesis adopts the alternate term. For the purposes of this thesis the ideal discussion is either unitary or adopts multiple perspectives. From experience, pluralistic and authoritarian discussions tend to complicate the development of an overview.

Term	Explanation	Example
Unitary	A single perspective is presented and considered correct.	Me
Authoritarian	Multiple perspectives are presented but only one is considered correct.	Me, maybe you
Multiple	Multiple perspectives are presented where each is considered correct separately. some attempts may be made to compromise.	Me and you, maybe us.
Pluralistic	Multiple perspectives are presented in a amorphous whole where the notion of correct no longer has meaning.	Me/Us/You

Table 3.2: Different types of type

The cohesion axis has no theoretical basis. It acknowledges that clarity is a requirement for communication. The stripped down interpretation of cohesion is "how hard is it to follow and to figure out the point?" Table 3.3 describes and provides examples of the terminology on the cohesion axis. Scholarly works are expected to be fully coherent.

Term	Explanation	Example
Incoherent	Lacking in organization, flow, and reasoning.	Stream of consciousness ramblings in a diary
Grouped	Some attempts at organization with the possibility of flow and minimal reasoning.	Opinion piece or response paper
Considered	Organized according to a consistent structure with reasoned arguments	Essay
Coherent	Organized with logical flow and significant reasoning.	Authoritative work

Table 3.3: Different types of cohesion

The acceptance axis is also intended to streamline the research process. A stripped down interpretation of acceptance is "does anyone value the model". Table 3.4 describes and provides examples of the terminology on the acceptance axis. Wide acceptance does

Term	Example
Individual	Me
Group	Reviewers from the Journals of Engineering Education
Faction	Engineering educators who use Problem Based Learning
Global	Engineering educators

Table 3.4: Different types of acceptance

not guarantee validity, even in the hard sciences. The *Encyclopaedia Britannica* entry for 'heredity' states that humans have 24 karyotypes even though the photographic evidence that supports this statement only shows 23. [97] It allegedly took over 10 years to convince biologists to look at the photographic evidence and change their resources. While the weaknesses of the peer review system must be acknowledged, it still serves the pragmatic purpose of introducing some level of quality control. Therefore this thesis assumes that more is better. Accordingly sources that are widely cited and discussed, which would accord them acceptance ranking of *global*, will be used wherever possible.

The substantiation axis tries to answer the question "How rigorously has the model been justified?" Table 3.5 describes and provides examples of the terminology on the this axis. The notions of rigour and substantiation can be exceedingly controversial. The different approaches are distinguished by different epistemological and ontological beliefs. In the case of engineering the selection of an approach is complicated by a lack of discussion on these issues. In practice engineers appear to adopt epistemological and ontological positions in a relatively pragmatic manner. Mathematical proof and logic take precedence in some cases while judgement and intuition do so in others. The pragmatic approach to an engineering thesis leads to the conclusion that sources should at least reach the *methodology* level of substantiation. An engineering thesis is a scholarly work within the hard sciences. The epistemology of science demands some form of methodology.

The goal axis tries to describe the objective of the model. Table 3.6 describes and provides examples of the terminology on the this axis. These definitions are based on a synthesis of numerous research papers [54, 163, 261, 86, for example], on the content of

Term	Explanation	Example
Opinion	No attempt at substantiation.	"I believe that...", "Everyone knows that..."
Investigation	Unverifiable, undirected attempts at substantiation.	"I asked some colleagues..."
Methodology	Verifiable, directed attempts at substantiation.	"I put together a survey and ran the results through a statistical software package."
Rigour	Verifiable, directed attempts at substantiation that have been reflected upon and deemed appropriate given the specific nature of the question being answered.	"Given the nature of this problem, interviews and a literature review was not appropriate. A survey, that did not incorporate open-ended questions, was chosen to flexibly constrain the responses."

Table 3.5: Different types of substantiation

the *Modelling in the Management Sciences* course offered at the University of Waterloo, and on group discussions related to issues within systems theory and complexity. The description of the goal axis concludes the introduction of the assessment model that will be applied to the major sources.

3.3 Assessing the sources

Three types of sources were investigated in the attempt to describe the current state of engineering education. The first type of source includes those discussion papers that provide summary statistics of the inputs and outputs of the engineering education process. The second type of source is the engineering education literature published in the form of books, journals, and conference proceedings. The third type of source is the documents associated with the accreditation of the undergraduate engineering programmes. All significant sources will be described using the assessment model outlined in section 3.2.

Term	Purpose
Categorization	Frames a discussion with a minimum of structure. May include some hierarchical features. Does not address issues such as influence.
Conceptual	Identifies high level components and the relationships or influences between them. Likely to include a small number of hierarchical structures.
Detailed	Further refines the conceptual model both in breadth and in depth. May begin the mapping from the model to that being modelled.
Interaction	Still further refinements. Contains sufficient mapping between the model and the subject to allow for decision and action.

Table 3.6: Different types of goals

3.4 Discussion papers

There are a number of discussion papers that provide summary statistics and counts describing engineering education and engineering in Canada. [34, 36, 172] The counts typically include:

- the number of applicants to university engineering programmes
- the number of students enrolled in university engineering programmes
- the number of students who graduate from university engineering programmes
- the number of students who obtain employment after graduation
- the number of individuals who register within the profession
- the number of disciplinary cases due to incompetence of individuals within the profession

These counts and statistics can be so simplistic as to fail to provide useful information. For example, the estimate of the number of students obtaining employment after graduation usually fails to account for whether or not the employment is within the profession. These numbers also fail to describe what happens during the interval between admission and graduation. Therefore, the discussion papers can not be used to assess how successful the engineering education system is at producing quality engineers.

3.5 Engineering education journals

Most of the articles published in the engineering education journals focus on the weaknesses within engineering education instead of providing a description of the state of engineering education. Therefore, these journal articles will be discussed in chapter 4.

3.6 Accreditation documents

The lack of applicable literature can be partially overcome by examining the engineering accreditation literature and processes. In Canada all engineering programmes must be accredited according to strict criteria. The United States is somewhat more permissive and allows programmes to call themselves "engineering" without accreditation. The number of programmes that take advantage of this permissiveness appears to be quite small. As described in Appendix D, many of the established engineering programmes with reputations for excellence have chosen to be accredited. Given this acceptance and the Canadian regulations the accreditation criteria describe global features that are shared by the majority of engineering programmes. They also represent an accepted vision of engineering education. Regardless of whether engineering educators agree with the accreditation criteria they are both aware of and affected by them.

At present there are three sets of accreditation criteria that can be used to describe the current state of engineering education. The CEAB Accreditation Criteria Procedures [32] are used in Canada. The ABET Conventional Criteria (ABETCC) [99, pp. 1-10] were used in the United States until the start of the 2001-2002 accreditation cycle when they were replaced by the ABET Criteria 2000 (AC2K). [99, pp. 32-34]

Each set of criteria claims to promote flexibility and innovation. The CEAB criteria state that the board "gives sympathetic consideration to departures from these criteria in any case in which it is convinced that well-considered innovation in engineering education is in progress." [32, section 2.2] Similarly, ABET claims the conventional criteria "are intended to encourage and stimulate and not to restrain creative and imaginative programmes. In any case in which EAC of ABET is convinced that well-considered experimentation in engineering educational programmes is under way, it shall give sympathetic consideration to departures from the criteria." [99, section I.B.1] As is discussed in section 3.6.4 the ABET2K criteria go even further towards promoting flexibility by specifying as few criteria as possible.

In order to create flexibility the accreditation criteria do not go into great detail. While statements about engineering education can be deduced from the criteria, these statements demonstrate the extent to which the criteria must be interpreted and their unsuitability as descriptors. For example statements 1, 2, and 3 were deduced from the CEAB criteria and statement 3 was deduced from the ABET2K criteria.

1. There exists a record maintained by the programme administration that all engineering gradates received a minimum of 225 AUs of contact time related to mathematics.
2. There exists a definition of demonstrated competence maintained by the programme administration.
3. There exists a record maintained by the programme administration that all engineering gradates have demonstrated competence in basic sciences.
4. At some point before graduation engineering students will have been exposed to one year of college level mathematics and will have had documented a demonstrated ability to apply knowledge of this mathematics.

Based on these statements the goal of a comprehensive overview of engineering education cannot be realized using the accreditation documents directly. The details of interpretation exist within the submissions made by the programmes to the accreditation organizations. Unfortunately the engineering deans and the accreditation organizations are unwilling to use this information to generate a composite and comprehensive view of the current state of engineering education. This reluctance may stem from concerns of confidentiality. The accreditation submissions in Canada include information such as personal details of faculty members, individual salaries, and the breakdown of the departmental budget. This information is interleaved with open information such as course content, teaching methods, and departmental goals. Neither the engineering deans nor the accreditation body appear willing to expend resources to separate and collate this information.

The accreditation documents could still provide valuable insight into how engineering and engineering education are conceptualized by influential engineering associations. However, neither accreditation body provides any rationale for their criteria or process. There is no publicly available documentation that describes why particular criteria have been included or excluded. Both organizations have produced questionnaires that candidate programmes are expected to use when documenting their activities. The ABET questionnaire is publicly available while that of the CEAB is not. In neither case is the rationale linking the questions to the criteria given. According to long time staff members at the CEAB there has never been a request made for the rationale behind the criteria or the questionnaire. [33]

Since they are not directly available, several steps were taken in order to access and analyse the conceptual models used by the accreditation boards. The first step was to represent as closely as possible the structure or lack thereof within the original documents.

3.6.1 Analysing the accreditation documents

The accreditation criteria embody the definitions of engineering and engineering education held by the accreditation boards. Therefore, the conceptual models can be inferred from the accreditation documents. The components of the conceptual model were extracted from statements that included the words *must*, *should* and *expected*. For example "*The engineering curriculum* must *culminate in a significant design experience...*" implies that the design experience is a component of the curriculum which is in turn a component of the conceptual model. The resulting conceptual models are presented graphically.

These conceptual models are relatively primitive. In order to organize the information into a more meaningful format, an engineering model was imposed upon the conceptual models derived from the accreditation criteria. This "standard" engineering model derives from studies of control or signal processing and is described in figure 3.2. This type of model is a "black box" because the process of interest is described by identifying the inputs and outputs of the model. An alternative method of describing a process would be to develop a detailed explanation of the mechanisms of the transformation. The inputs are those components which will be transformed by the process and which cannot be controlled. The parameters affect the process and can be controlled. The process transforms inputs and parameters into desired and undesired outputs. It isn't directly described in a black box model. The outputs are the intended and desired results of the process and the undesirables are the unintended and undesirable results of the process.

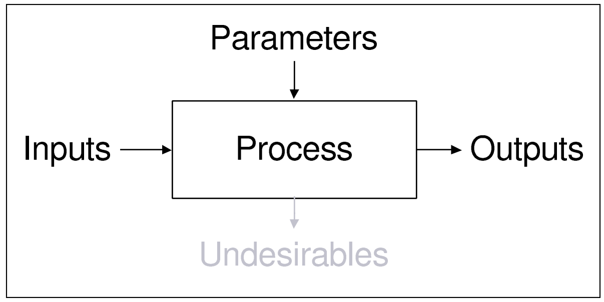

Figure 3.2: Basic engineering process model

Figure 3.3 depicts a model of engineering education based on the generic model shown in figure 3.2. This model does not include any undesirable outputs. Such outputs may

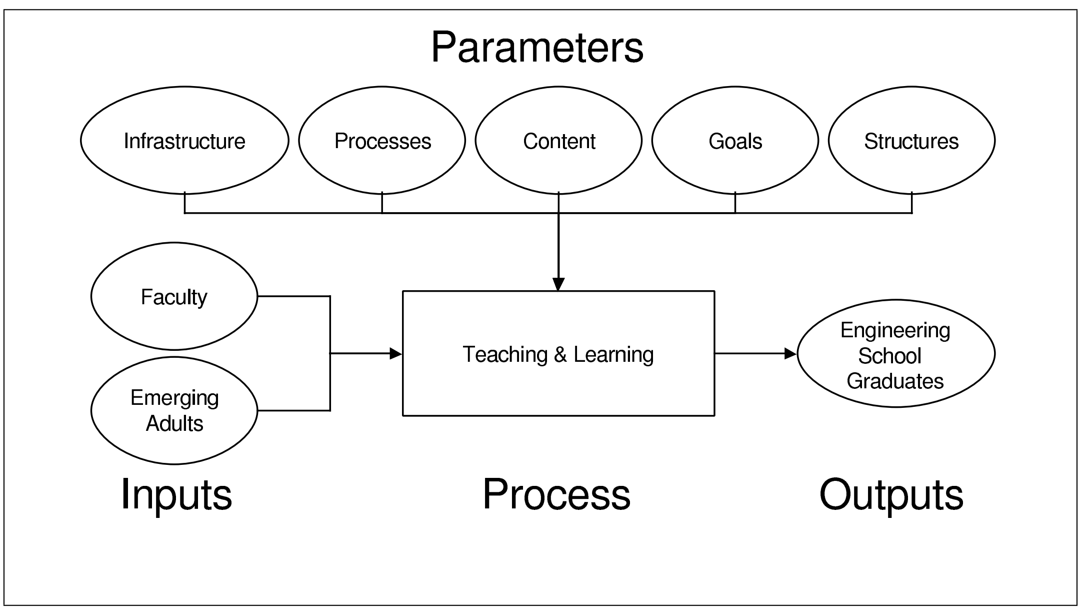

Figure 3.3: Engineering process model of engineering education

include students who failed or transferred out of the programme. These outputs were omitted from the model as the accreditation criteria on which the model is based focus solely on that which is desired of engineering education. The majority of the components of this new model are parameters to the process. The choice of parameters was influenced by the principles of systems theory and of academic course design. Systems theory promotes examining structures and processes to further system understanding. [153, 113, 216, 156] The techniques of academic course design emphasize the importance of goals and varying types of context. [242] A brief description of each input, parameter, and output follows.

Faculty Individuals hired to instruct and mentor students, including professors, lecturers, and sessionals.

Emerging adults Engineering undergraduate students. This term was chosen because students are more than simple seekers of knowledge. It is a relatively new term in developmental psychology and sociology that acknowledges the distinct needs and characteristics of those who are changing social roles from adolescent to adult (see section 6.13.3). This definition excludes mature students and unusually young students. These individuals are a minority of engineering students therefore this exclusion is considered justified.

Infrastructure Physical and human resources that facilitate the process including libraries, laboratories, technical staff members, university administration, etc.

Processes Repeating patterns of activity associated with goals. Examples include admissions, and assessment.

Content The material that is to be imparted to the student including mathematics, science, problem solving, etc.

Goals Statements of purpose that address more abstract aspects of the programme. Goals can be interpreted as criteria that may apply to any aspect of the model. In general the goals identify characteristics that would be desirable in an engineering graduate.

Structure The complement of processes. In this instance, structure refers to the entities that make up the department. The processes within the department are undertaken by the various structures developed for this purpose. Examples of structure include the offices of the department chairs and associate chairs and SAGE[2].

Engineering school graduates Individuals who have, ideally, incorporated the content, used the infrastructure, been part of and been subjected to the processes and structures, and embodies the goals.

This model can be criticised as an attempt to apply the engineering hammer to the nail of education. While the fit between the engineering model and teaching and learning may not be perfect, the engineering model may still provide useful insights when applied to the conceptual models developed from the accreditation criteria.

For each accreditation document a two stage analysis is performed. The first stage examines the text of the document without reference to any external models or assumptions. This analysis is intended to reveal the conceptual model used by the developers of the criteria. Specific criteria or constraints are not considered part of the conceptual model. This model contains only those elements subject to the constrains and criteria. These models are generally presented as collapsed hierarchies in bubble-diagram form. The second stage of the analysis reinterprets the document according to the model presented in figure 3.3. In this reinterpretation the goal is to link the elements of the original conceptual model, and in some cases their associated constraints and criteria, with components of the new model. The goal of this stage of the analysis is to determine which aspects of engineering process model of engineering education are being addressed by the accreditation groups.

3.6.2 CEAB Accreditation Criteria

The CEAB divides the system of interest into two categories, "Curriculum Content" and "Program Environment". The criteria are grouped by these categories.

The CEAB document includes roughly the same number of "should" and "must" statements and the criteria vary in rigour. Some, such as those related to curriculum content, are very specific. Many others allow for significant interpretation. Examples of the criteria include:

[2]See section 5.1.8.2.

> "*The engineering curriculum* must *culminate in a significant design experience…* "[32, section 2.2.4]

> "*The faculty devoted to the program* must *be large enough to cover, by experience and interest, all of the curricular areas of the program…*" [32, section 2.3.2]

> "*In assessing the time assigned to various components of the curriculum, the actual instruction time exclusive of final examinations* should *be used.*" [32, section 2.2.10]

The categories which grouped the criteria and the criteria themselves were used to develop a conceptual model that mirrors the criteria as closely as possible. This model is depicted in figure 3.4. Relative to the other accreditation criteria, the phrasing of the CEAB criteria allows significant latitude. In order to maintain parity, figure 3.4 includes both the mandatory and optional elements specified by the criteria. Without the optional elements the CEAB criteria focus primarily on the curriculum with some attention given to administrative structures, processes, and faculty members. The optional elements incorporate the environment in which the programme is delivered.

This initial representation of the CEAB conceptual model is difficult to interpret because of its lack of structure. Using solely the text of the criteria an engineering programme consists of curriculum and the all-encompassing programme environment. To compensate for this lack of structure the basic model was reformulated in terms of the engineering model depicted in figure 3.3. This new model is depicted in figure 3.5. Given the focus on curriculum, the majority of the original elements fall under the *content* component. Structures and infrastructure are the next most populated components. The criteria do not define any elements that fall within the *process* component.

3.6.3 ABET Conventional Criteria

The ABET Conventional Criteria (ABETCC) will be replaced by the Criteria 2000 starting in the 2001-2002 accreditation cycle. Accordingly the ABETCC offers the best description of the current state of engineering education in the United States. ABET offers both advanced and basic level accreditation criteria. For compatibility with the CEAB, this

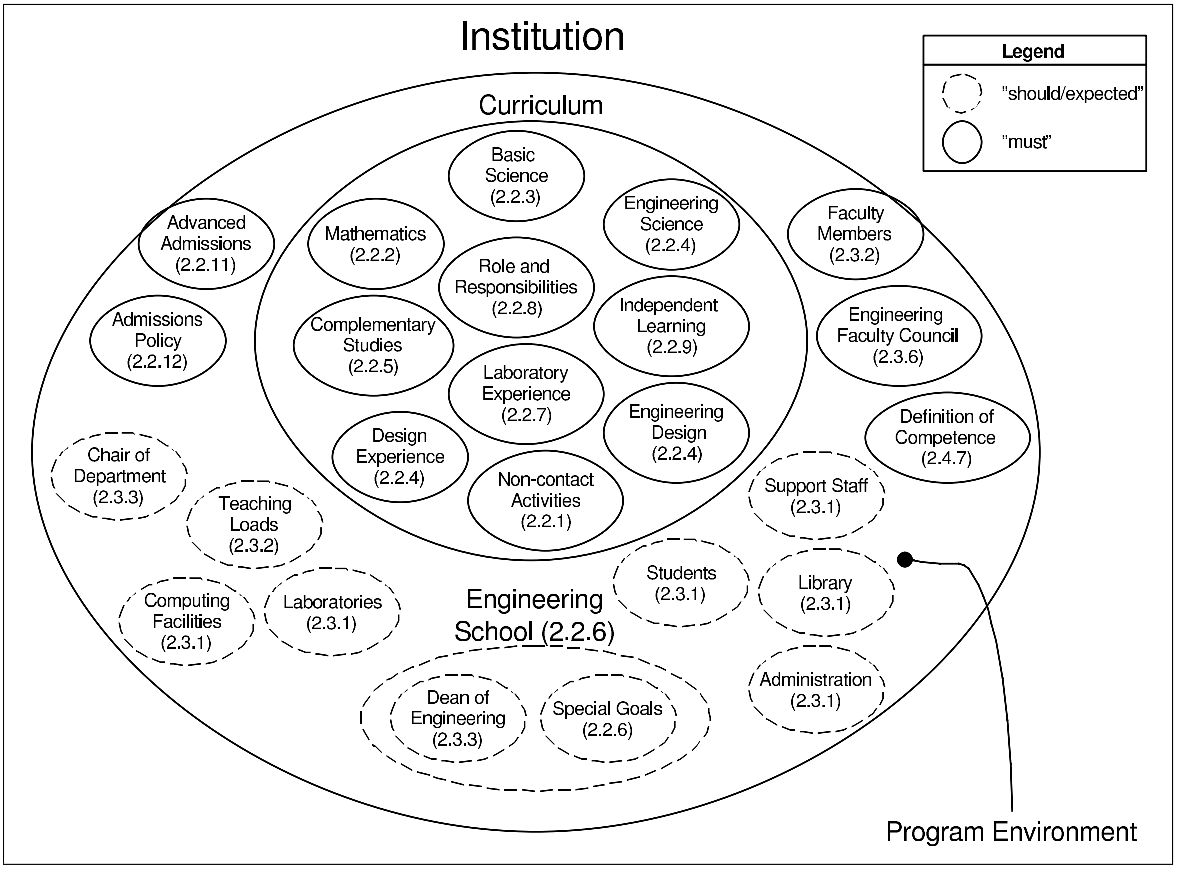

Figure 3.4: CEAB conceptual model of engineering education

document describes the advanced criteria. Unlike the CEAB, the ABET documentation includes discipline-specific criteria. These criteria generally focus on the curriculum and administration aspects of engineering education. Again, for compatibility with the CEAB, these criteria were not included in the analysis.

The ABET Conventional Criteria are significantly more precise than the CEAB criteria. Examples of ABETCC statements include:

> "*Teaching loads* must *be consistent with stated program objectives and expectations for research and professional development.*" [99, section I.C.1.e]

> "*Studies in mathematics* must *be beyond trigonometry and* must *emphasize*

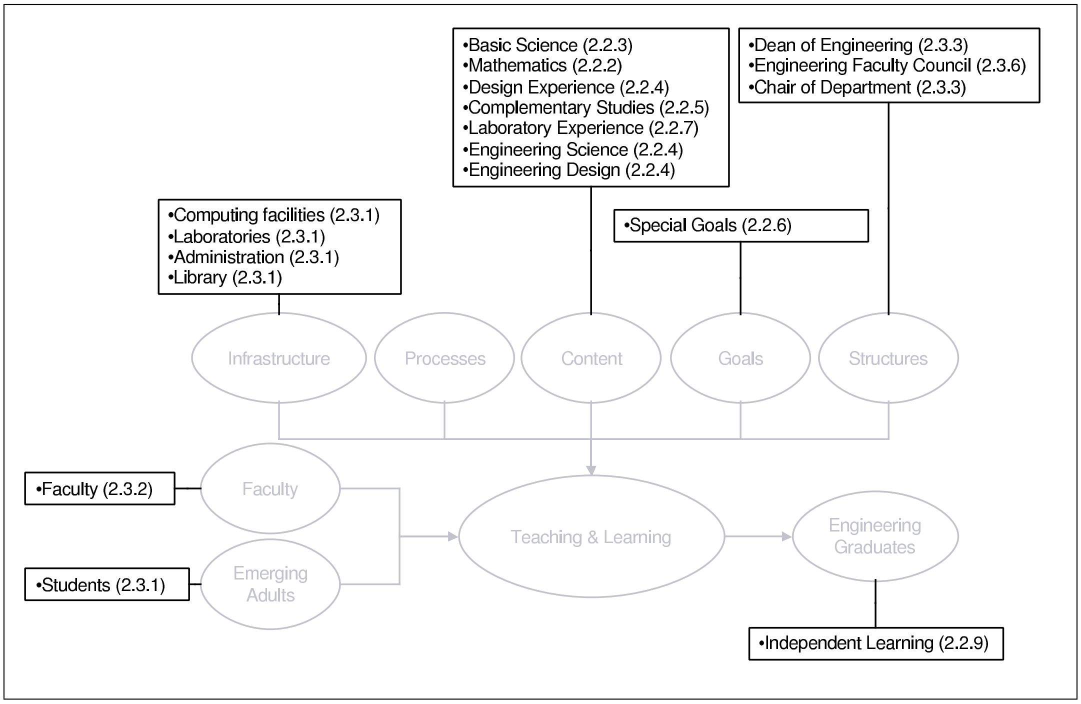

Figure 3.5: Reinterpretation of the CEAB model

> *mathematical concepts and principles rather than computation.*" [99, section I.C.3.d(1)(b)]

The ABETCC does not include the optional components present in the CEAB criteria. A conceptual model was developed from the ABETCC document. It attempts to represent as directly as possible, the organizing principles of the criteria. This model is depicted in figure 3.6. The ABETCC does not accord the curriculum the same importance as does the CEAB criteria. The ABETCC definition of a programme is significantly broader and includes elements that the CEAB considers part of the programme environment. The initial conceptual model representing the ABETCC is difficult to interpret because of the lack of interactions and the small number of organizing categories. Again the engineering model depicted in figure 3.3 is used to reinterpret the criteria. The resulting model is depicted in figure 3.7. In keeping with the stricter nature of the ABETCC, the content component is the most populated element. The infrastructure, faculty, and emerging adults components

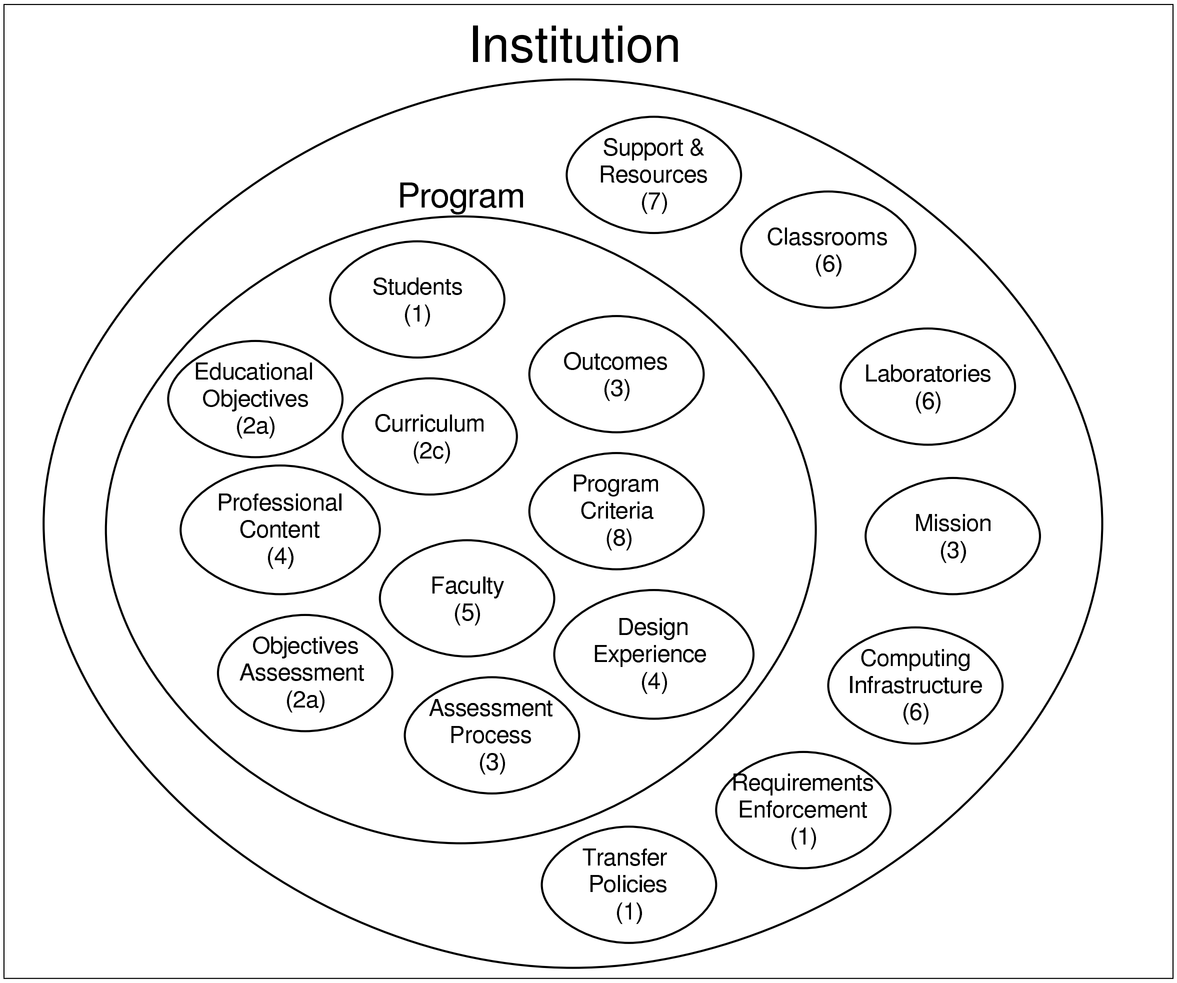

Figure 3.6: ABETCC conceptual model of engineering education

are similar to those of the CEAB model. The two models differ substantially with respect to the processes and structures components. The ABETCC contains a number of policy elements but no structural elements. By contrast, the reinterpretation of the CEAB criteria revealed a strong emphasis on structure over policy.

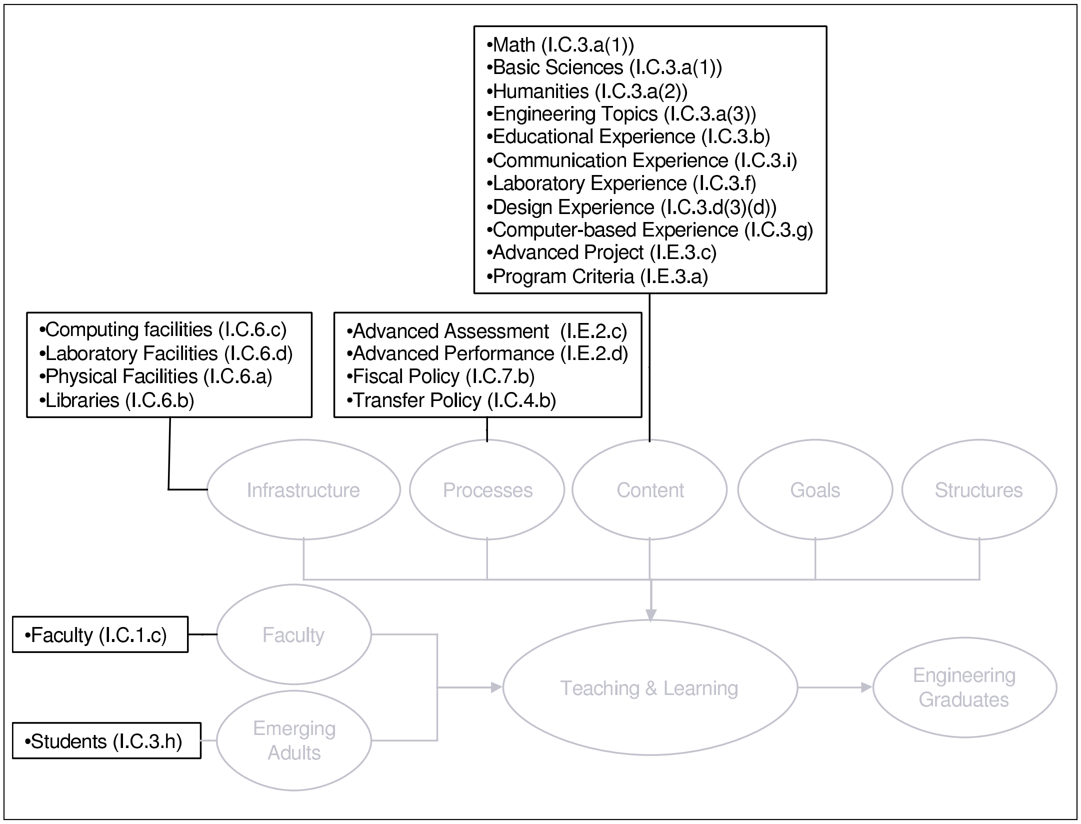

Figure 3.7: Reinterpretation of the ABETCC model

3.6.4 ABET Criteria 2000

The ABET Criteria 2000 (ABET2K) dominated American discussions of engineering education in the late 1990s. The new criteria were intended to be a radical shift in engineering accreditation. Faculty members and administration were concerned that the new criteria would require a complete rethinking of programmes and curricula.

A close examination of the two sets of criteria reveals that the main difference is in the extent to which the criteria require interpretation. The ABETCC states that programme administrators and accreditors are expected to exercise judgement but the detailed criteria in ABETCC promote a dogmatic approach to accreditation. The ABET2K criteria are the conventional criteria with the details removed. Therefore, the ABET2K will require more interpretation but does not otherwise represent a radical shift in accreditation.

The ABET2K criteria are phrased as outcomes. These outcomes make up almost half of the text of the document which is significantly shorter than the other accreditation documents. The common preface to all of the outcomes is "Engineering programs must demonstrate that their graduates have…". Examples of specific ABET2K outcomes include:

1. …an ability to apply knowledge of mathematics, science, and engineering
2. …an ability to design and conduct experiments, as well as to analyse and interpret data
3. …an ability to design a system, component, or process to meet desired needs
4. …an ability to function on multi-disciplinary teams

A conceptual model representing the ABET2K document is depicted in figure 3.8. While ABET2K was intended to allow for interpretation, it nevertheless incorporates a strict, detailed model of engineering education. Compared to the other accreditation criteria, it has fewer components related to the curriculum. It makes up for this with a significantly more components related to the programme. With respect to the programme environment, ABET2K is similar to the other accreditation criteria.

The results of reinterpreting the criteria using the model from figure 3.3 is depicted in figure 3.5. Compared to the other accreditation criteria, ABET2K is significantly more balanced. The content, infrastructure, and processes components all contain similar numbers of elements. In keeping with its focus on outcomes ABET2K includes more elements within the goals component than the other criteria. The ABET2K criteria shares with the ABETCC a focus on processes in lieu of structures.

3.6.5 Overview of the accreditation documents

The assessment model developed in section 3.2 can be applied to the set of accreditation criteria. The result of this assessment is presented in figure 3.10 and further described below.

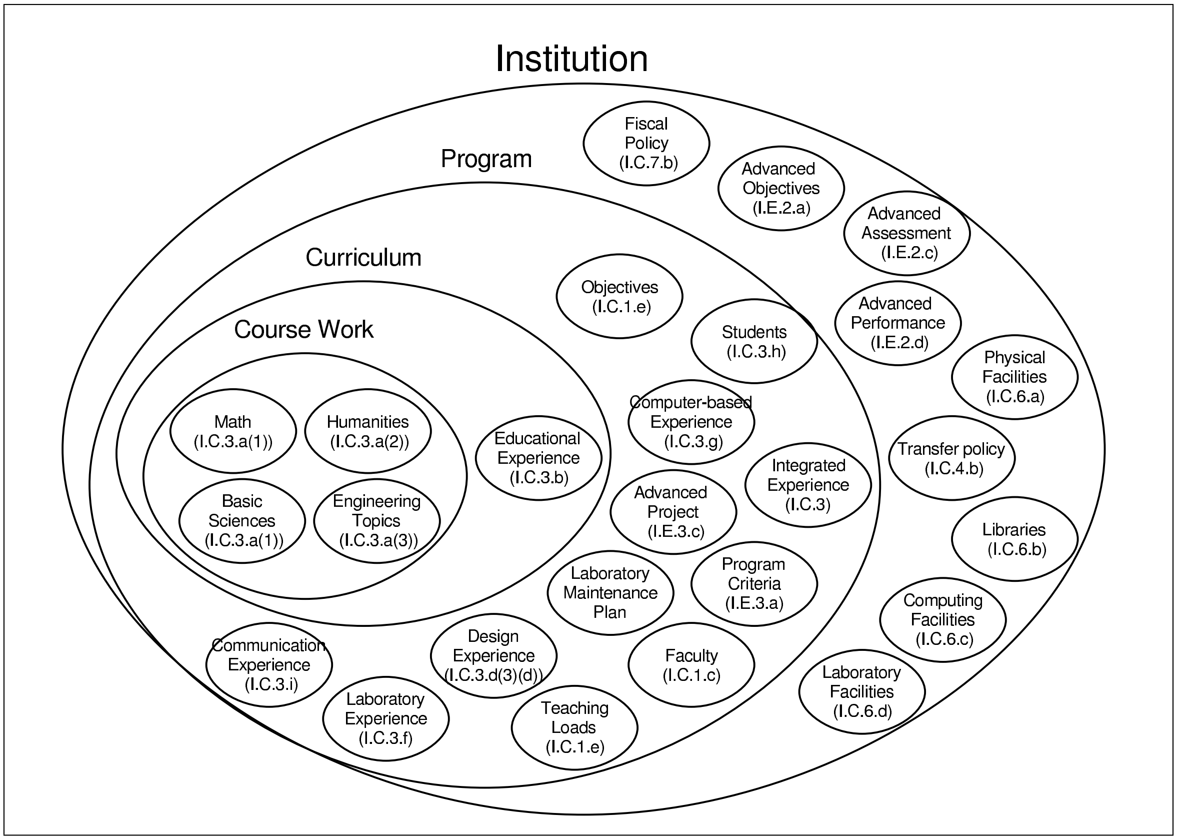

Figure 3.8: ABET2K conceptual model of engineering education

Scale The majority of the accreditation criteria address either curriculum or programme environment. This is sufficient to fall into the *narrow system* level. On occasion the criteria discuss issues at larger scales, such as faculty, university, and industry, but the majority of the discussion focuses on the narrow system.

Type The criteria cover a number of different perspectives ranging from assessment, to policies, to manpower. Accordingly they score near a *multiple* in this category. What is lacking is any attempt to relate the different types. For example, manpower and university policies will affect the ability of the programme to control its own curriculum. Also lacking are links between the perspectives and the common goal of accreditation.

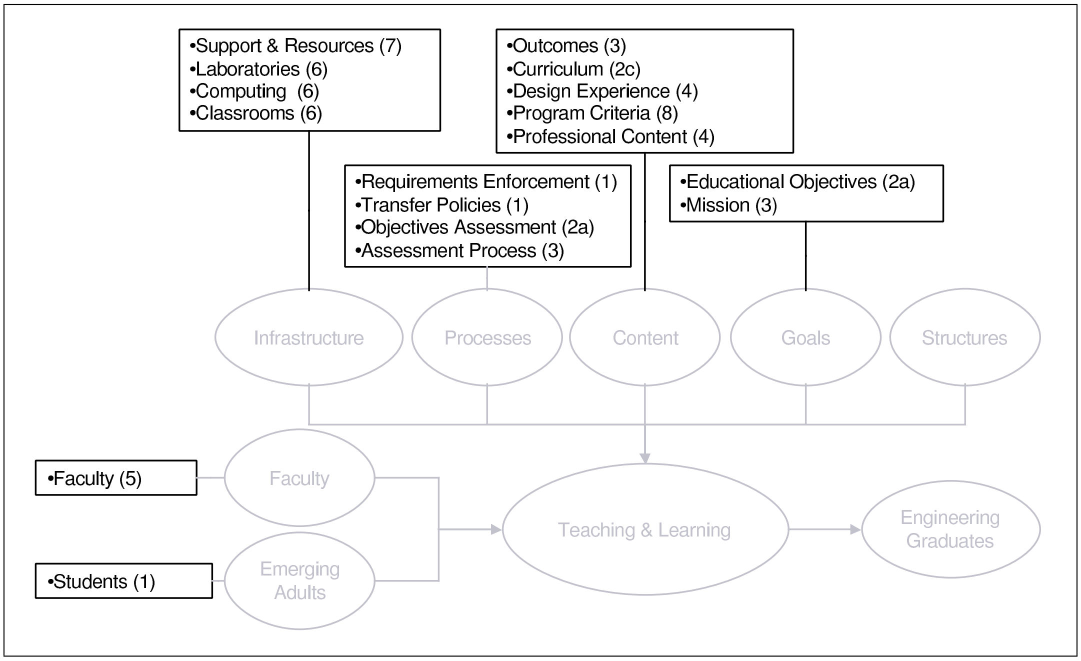

Figure 3.9: Reinterpretation of the ABET2K model

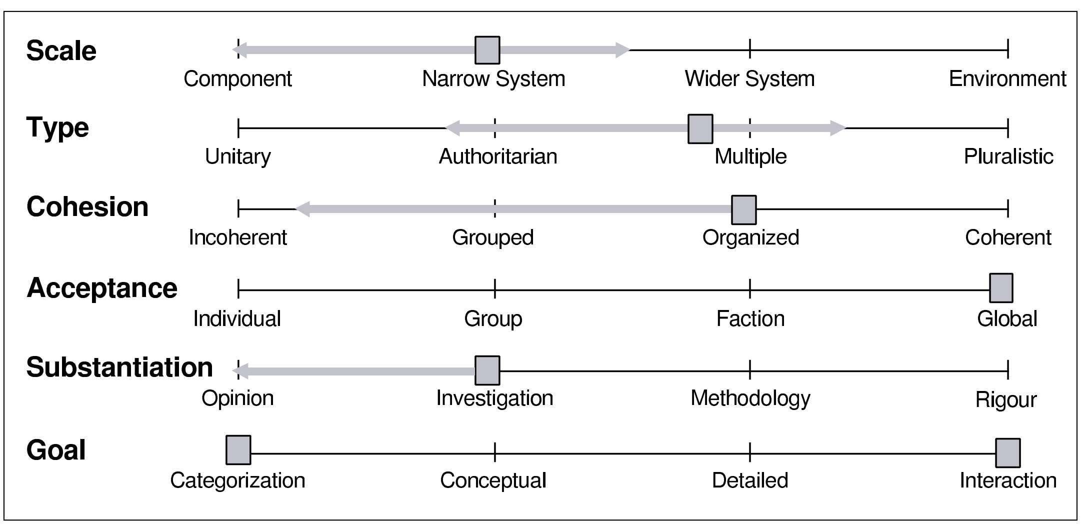

Figure 3.10: Assessment of a composite of the accreditation criteria

Cohesion The majority of the criteria fit neatly into a relatively simple hierarchy. This fit leads to a score of *organized*. However within the criteria the organization breaks down. The discussions jump in a seemingly randomly way across different scales and types. While the criteria deserve credit for taking a view that is both broad and deep, the lack of structure renders the documents less coherent.

Acceptance All engineering educators, even if they do not agree with them, have to accept the accreditation criteria. Therefore they were assigned a score of *global*.

Substantiation The accreditation documents do not contain any evidence of substantiation.

Goal As depicted in figures 3.4, 3.6, and 3.8, the models underlying the criteria have a few organizing principles, at best. Therefore they are described as *categorization* models. However the criteria are also used during an accreditation visit to assess the programme. As such the criteria are considered by the accreditation bodies as *interaction* models[3].

The initial models developed from the three sets of accreditation criteria have another characteristic in common. The models are limited to those aspects of engineering education over which the accreditation boards have some authority. The accreditation boards do not and should not dictate teaching style. Therefore, it is unsurprising that the models do not include teaching style as a component of engineering education. As a result the models do not provide a comprehensive description of engineering education.

The re-interpreted models, shown in figures 3.5, 3.7, and 3.9, also demonstrate some interesting similarities and differences. The greatest concentration of the components of the accreditation models relate to the content components of the engineering model. Given that an engineering programme is commonly taken as a curriculum, which in turn may be considered as a combination of content and structure, this concentration is not surprising. The second highest concentration of components relate to infrastructure. This may be

[3] In this instance both scores are recorded. Doing so emphasizes that the same model may be perceived differently depending on the purposes to which it is put.

explained by the nature of accreditation. From the perspective of an outside observer infrastructure is something that is both visible and verifiable.

The re-interpreted models also highlight an interesting difference between the Canadian and American approaches to accreditation. As shown in figure 3.5, the CEAB criteria include three structural elements and no process elements. In contrast, as shown in in figure 3.7, the ABETCC criteria include four process elements and no structural elements. Where the CEAB focuses on structure, ABET focuses on process. One possible explanation for this difference is the relative homogeneity of the Canadian engineering programmes relative to that of those in the United States. In Canada, all engineering programmes are at the advanced (or honours) level and take place in universities. This homogeneity may allow the CEAB to make assumptions about processes and focus on the enabling structures. In the United States, engineering programmes can be accredited at either a basic or advanced level. These programmes can also be delivered at either colleges or universities. This heterogeneity may restrict the structures that ABET can mandate. The solution they have chosen is to mandate processes.

3.7 Conclusions

The current form of engineering education has remained fundamentally unchanged for 50 years. The forms of the institutions in which engineering education takes place have been relatively static for even longer. During the last 40 years vast resources have been allocated to engineering programmes and research. One would assume that out of some desire for accountability and history a picture of engineering education would emerge. This has not happened.

Using only publicly available documentation it is not possible to develop a comprehensive description of the current state of engineering education. Reports that provide mainly summary statistics or counts associated with engineering education raise more questions than they answer. The engineering education literature mainly focuses on the gaps within engineering education. The engineering accreditation criteria, which are widely known and highly influential, provide a description that is neither comprehensive nor useful. In short there is, at present, no way to know the current state of engineering education.

Chapter 4

The gaps within engineering education

This chapter discusses those aspects of engineering education that are in need of improvement. This discussion is based primarily on the major reports on engineering education but also briefly describes the contributions of the articles in the engineering education journals. This chapter builds on the work done in chapter 3.

The goal of this chapter is not to present a complete, comprehensive analysis of the various documents that criticise engineering education. Instead it highlights those aspects of the documents that are most relevant to a broad discussion of engineering education. An entire Master's thesis could be devoted to understanding the beliefs and opinions that underlie any of the major reports.

4.1 Journal articles and conference proceedings

A major difficulty encountered when researching engineering education is that much of the documentation is either missing or has not been catalogued. This is particularly true of Canadian documentation. At present the Canadian library system does not have a complete collection of the proceedings of the Canadian Conference on Engineering Education. This is the only conference of its kind in Canada. Tantalizing references are made in the literature to events such as the Canadian Engineering Centennial Convention. Again the proceedings of these events cannot be found.

The engineering education journals are significantly more accessible than the conference publications. The primary journals consulted during this research were the *Journal of Engineering Education* and *Chemical Engineering Education*. Their contents were supplemented by articles from *PRISM Magazine*, *IEEE Transactions on Education*, the *Journal of Professional Issues in Engineering Education and Practice* and the *International Journal of Mechanical Engineering Education*. A more complete discussion of the journals used in this research can be found in section A.3.

The majority of the searches through the sources were electronic. To develop a general understanding of the state of research into engineering education, all of the articles appearing in volumes 88, 89, and 90 of the *Journal of Engineering Education* were examined. These articles, along with those revealed through electronic or citation searches, were assessed using the model described in section 3.2. The results of this assessment are presented in figure 4.1 and further described below.

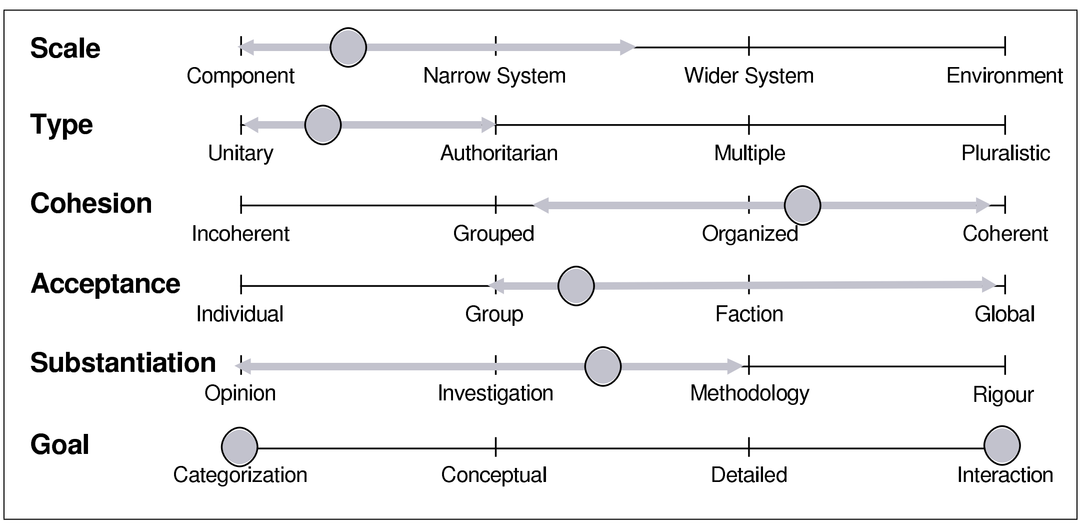

Figure 4.1: Assessment of the articles in engineering education journals

Scale The vast majority of the articles focus on a particular course or sequence of courses. The topic is generally treated in isolation. In the July 2001 issue of the Journal of Engineering Education, half of the articles discussed a single course with little or no reference to any kind of context and a third of the articles discussed teaching and learning within a single department or faculty. Very infrequently an article will address issues that pertain to the wider system, such as relations with industry. In general the articles score somewhere between *component* and *narrow system*.

Type In the same way that they tend to focus on a single component the articles tend to adopt a single perspective. Depending on the degree of substantiation other perspectives may be referenced in support of the dominant perspective. The rare articles that discuss multiple perspectives tend to be comparisons of teaching styles to the same material. For these reasons the article score between *unitary* and *authoritarian*. [123, 90, 196, 178, 129, for example]

Cohesion The articles all appear in the peer reviewed academic journals listed earlier. Accordingly they all must be able to present their contributions in an understandable way in a relatively small space. Accordingly the articles generally rate between *organized* and *coherent*.

Acceptance All that is known for certain about the articles is that they meet the criteria of the editorial boards and the reviewers. A formal meta-analysis of the engineering literature analysed the articles that appeared in the Journal of Engineering Education between 1993 and 1997 and revealed that the literature is less cohesive and the popular authors less qualified than would be expected.

> "Twenty issues of the Journal of Engineering Education from 1993 through 1997 were analysed. ... The average number of usable references per article was 15.2. The mean number of times a source was cited is one. Only 20 sources were cited five or more times. Twenty-four authors or organizations were cited ten or more times. Of the most-cited authors 48 percent do not have a degree in engineering, computer science or engineering technology. The keyword and citation analyses showed that the Journal has great breadth of both content

> and sources for references. The mean number of times articles published in the Journal during 1993 and 1994 were later cited in the Journal was 0." [266]

Since Wankat's meta-analysis indicated that the articles are rarely cited the articles scored slightly more than *group*.

Substantiation As peer-reviewed materials the articles all exhibit some level of substantiation. That having been said there is a wide variety of scores among the articles. Some use formal investigative methodologies while others are little more than opinion buttressed by experience. The need for improvements in substantiation has been acknowledged by the editorial boards of some of the engineering journals.

> "If the *Journal of Engineering Education* is to attract significant attention, it must contain scholarly articles possessing enunciation of education principles, not simply superficial analyses of classroom data or experiments." [94]

> "The *International Journal of Engineering Education* has recently decided to accord more emphasis to engineering education research that has a clear theoretical and conceptual basis, and that reports results that have wider application to teaching practice and student learning." [149]

In May, 2001 similar sentiments were expressed by the editorial board of the IEEE Transactions on Education. The editors stated that they were not interested in reviewing papers including "...Significant technical content with little or no substantive pedagogic information." [49] In general the more recent articles on engineering education score between *investigation* and *methodology*. It is hoped that the new editorial policies will improve this score.

Goal The articles had a range of goals. Some articles, including those that focus on the activities within a particular course, fall at the *implementation* end of the spectrum. Those that address broader issues, such as the direction for engineering education or the need for teacher training for professors, generally score no more than a *categorization*.

4.2 Major reports

Since the last major evolution of engineering education (see section 3.1) a small number of reports have been produced that purported to identify and propose solutions to problems with engineering education as a whole. All of these reports propose strategic changes to the engineering education system. In general they base their proposals on some assessment of the gaps within the engineering education system at their time of writing.

The United States has produced a number of major reports that criticize and propose remedies for engineering education. Of these only the Grinter Report, based on a citation analysis, has had a major impact on the practice of engineering education. [48] The remaining publications have generally repeated the messages of the Grinter Report. This is somewhat alarming as the Grinter Report was released in 1955. The only substantive changes have been to call for increased use of computers. In Canada, major reports in the same vein as the Grinter Report are a relatively new phenomenon. Since 1990 three such reports have been released. Prior to 1990 there is reference made to a single report released in 1985. This section will discuss in detail the three recently published Canadian reports as well as the Grinter report.

4.2.1 *Report on the Evaluation of Engineering Education*

The Grinter report was the first major report on engineering education after the second world war. Over the last 45 years it has exerted significant influence on engineering education in the United States. It was authored by a 45 person committee of the American Society for Engineering Education (ASEE). At 21 pages it includes four references, all of which are to previous ASEE work.

The Grinter Report appears to have established a standard format for discussions of engineering education. It is based entirely on opinion and supposition with no attempts to investigate its claims. It emphasizes the importance of a number of aspects of the selection and development of the faculty and the content of undergraduate curriculum. The report also has a supplementary section on graduate studies. It does not discuss implementation issues or allow for alternative perspectives.

The influence that the Grinter Report has had upon engineering education can be inferred from a comparison between its recommendations and the sets of criteria created by the accreditation boards. The accreditation criteria of the CEAB and ABET read like expanded versions of the Grinter recommendations. Each of the Grinter recommendations can be matched to a criterion or set of criteria within the CEAB and ABETCC criteria. These matches are displayed in table 4.1. The full text of the third recommendation and the matching CEAB and ABETCC criteria are given below.

Grinter	**CEAB**	**ABETCC**
1	2.2.2, 2.2.3	I.C.3.a(1)
2	2.2.4	I.C.3.a(3)
3	2.2.4	I.C.3.d.(3)(d)
4	*not covered*	*not covered*
5	2.2.5	I.C.3.a(2)
6	2.2.5	I.C.3.i
7	2.2	I.B.1

Table 4.1: Correspondence between the Grinter Report and the accreditation criteria

Grinter #3 An integrated study of engineering analysis, design, and engineering systems for professional background, planned and carried out to stimulate creative and imaginative thinking, and making full use of the basic and engineering sciences.

CEAB 2.2.4 The engineering curriculum must culminate in a significant design experience which is based on the knowledge and skills acquired in earlier course work and which preferably gives students an exposure to the concepts of team work.

ABETCC I.C.3.d.(3)(d) Each educational program must include a meaningful, major engineering design experience that builds upon the fundamental concepts of mathematics, basic sciences, the humanities and social sciences, engineering topics, and communication skills...focuses the students attention on professional practice and is drawn from past course work.

The close mapping between the recommendations and the criteria imply that at some point the accreditation organizations took notice of the Grinter report.

The report is not organized around any recognizable conceptual model. The closest the report comes to having a conceptual model is its table of contents.

1. Objectives of Engineering Education and their Implementation (1 page)
2. The Selection and Development of an Engineering Faculty (4 pages)
3. Curricular Content as Related to the Objectives of Engineering Education (6 pages)
4. Evolution of Engineering Curricula (2 pages)
5. Special Factors that Influence Undergraduate Educational Achievement
6. Foreign Students (1 page)
7. Graduate Study in Engineering (4 pages)
8. Conclusion (1 page)

As discussed in section 3.6.5 the limited nature of the conceptual models that underlie the accreditation criteria can be partially excused by their restricted purpose. In the case of this report a similar excuse does not hold. The committee that produced the Grinter report was charged with investigating the entirety of engineering education. There is no justifiable reason for the lack of an explicit, comprehensive, and robust conceptual model of engineering education in their report.

The impact of the Grinter report on engineering education cannot be understated. It is the unacknowledged basis for the contemporary accreditation criteria. The issues it raised have been repeated in every subsequent report. While it has had positive impacts its negative impacts may be more telling. As the first major report it was in the position both to frame and to call for further and more detailed investigations into engineering education. By not developing a broadly useful conceptual model it allowed discussions of engineering education to lack coherence. By failing to recommend further research it has implicitly allowed discussions of engineering education to remain exercises of opinion rather than fact.

4.2.2 *The Future of Engineering Education in Canada*

This report was produced jointly by the Canadian Council of Professional Engineers and the National Committee of Deans of Engineering and Applied Science. Accordingly it focuses on both the state of the profession and on the state of engineering education. The report, authored by a 13 person task force, was delivered in October, 1992. The qualifications of the task force members are not known.

The report, including references and acknowledgements, is 49 pages in length. It includes nine figures and three tables. All of the figures, save one, are summary statistics. These statistics describe various aspects of professional engineering registration, engineering undergraduate enrolment and graduation, and engineering faculty membership. The content of the three tables is similar.

The report cites 26 references. Of these seven relate directly to engineering education. Six of these are American and one is Canadian. The majority of the remaining 19 references discuss the state of the engineering profession in North America and abroad. Eight of the references are from other countries.

The report begins by summarizing the state of engineering practice and engineering education. The summary raises a number of "standard" observations that are summarized in table 4.2. The disturbing aspect of this section of the report is the complete lack of

Observation	**Explanation**	**Substantiation**
Knowledge explosion	Knowledge begets knowledge; rapid generation of ideas; faster product cycles	None
Competition	Among different disciplines; across international boundaries	None
Globalization	Competition without protection	None
Impact of technology	Creates and destroys jobs; must understand impact before implementation	None
Environmental concerns	None	None
Infrastructure renewal	Roads, bridges, ports, etc. have outlived their design life	None

Table 4.2: "Standard" observations regarding the future of engineering

quantifiable evidence. This is not to say that quantifiable evidence is the only sort with value. There is however a need for balance between opinion and evidence.

The report then turns to a presentation of what is known about the practice of engineering and the education of engineers. The measurements include:

- Registration of professional engineers
- The categories of work of professional engineers (including non-engineering)
- The percentage registered professional engineers who are women
- Engineering degrees awarded in Canada, the USA, and Japan
- Enrolment in engineering programmes
- Degrees awarded by engineering programmes
- The number of accredited engineering programmes

For comparison purposes the report discusses the states of engineering and engineering education in the US, the UK, France, Sweden, and Australia. The discussion for each country, save the US, is a single paragraph that describes the content of a single report. The United States receives two paragraphs that too describe a single report. None of the discussions relate the experiences or conclusions of the foreign report to the Canadian situation. All serve merely to confirm that other countries are also investigating engineering and engineering education.

The report now turns to a discussion of engineering education. It begins by presenting a unique schematic diagram that describes the Canadian engineering education system. This diagram traces the path followed by students from pre-school through to continuing education. The components of the model include:

- Pre-school
- School
- CEGEP
- Undergraduate Program
- Master's Program
- Doctoral Program
- Pre-professional Experience
- Supervised Professional Experience
- Engineering Practice
- Continuing Education

Having presented this model the report then proceeds to ignore it. Instead it discusses:

- Pre-university education
- Undergraduate engineering education
- Graduate engineering education
- Professoriate

- Funding
- Governance
- Engineering profession
- Continuing education
- Supervised industrial experience

However it presents conclusions in terms of:

- Pre-university education
- University education: Undergraduate Engineering Programs
- Graduate engineering programs and students
- Engineering faculties and universities
- Engineering professoriate
- Post-university

And the recommendations are organized by stakeholder. How these stakeholders were identified is not discussed. The stakeholders include:

- Engineering Faculties
- Other Faculties
- Universities
- Community Colleges
- Government
- Industry

The change in presentation is not discussed in the report. One interpretation is that this is symptomatic of the difficulties encountered when discussing the engineering education system.

Because of the large number of components the remainder of the discussion contains surprisingly little content. There is insufficient space, and one can assume there was insufficient time, for a more complete discussion of each component of the model. For the purposes of this thesis only recommendations related to the undergraduate programme, the engineering faculties, and the engineering professoriate are of interest. Each of these eleven recommendations will be described or quoted and then discussed.

Recommendations 1...3

The first three undergraduate recommendations focus on broad resource issues. They promote enlarging capacity, lowering student-to-staff ratios, and updating teaching equipment. Two aspects of these recommendations are problematic. The recommendation is that teaching equipment be made "...commensurate with industrial standards." There is no evidence given to support the notion that the standards of industry are more appropriate for learning engineering. One could argue that using analogue oscilloscopes provides a better understanding of electrical signals than working with digital scopes.

The rationale behind lowering the student-to-staff ratios is "...to provide better instruction in design and unstructured problem solving." While the sentiment is noble there is no evidence that a lower ratio would have this result. One could just as easily make the case that higher ratios promote independent learning and the ability to work without supervision, both of which are seemingly desired abilities. The recommendation suggests that increased use of engineering graduate students could be used to meet this goal. This suggestion may be at odds with the desire for improved teaching skills in the professoriate. Unfortunately there is no evidence to support or refute the claim that graduate students are an effective teaching force.

Recommendation 4

> "The broad base of the Canadian engineering programs must be preserved to ensure that engineering graduates are adaptable and able to cope with technological and societal changes. Undue specialization should not occur at the undergraduate level. Specialization is more appropriately introduced at the graduate level." [31, Undergraduate Engineering Programs Recommendation 4]

The recommendation ignores the current structure of engineering faculties and funding agencies. Both are oriented around disciplinary specialization. The lack of definition of "undue" is also problematic. Given that there is no measure of the current levels of specialization defining the term will be difficult. The report is clearly unaware of past efforts to accomplish this objective. These efforts were a resounding failure. This failure is largely blamed on industry who, while they may claim to desire generalists, will not hire them after graduation. Students with the choice of specializing or remaining general also voted with their enrolment. Given the choice their preference was for specialization, and by extension employment. [219]

Recommendation 5

> "The engineering curricula should be reviewed and restructured, as appropriate, to broaden the scope of programs for engineering students." [31, Undergraduate Engineering Programs Recommendation 5]

This recommendation follows from the basic premise that a broad scope is preferred.

Recommendation 6

> "Consideration should be given to the integration of mathematics and science into engineering courses more on an as-needed basis rather than this material being taught primarily in separate courses." [31, Recommendation 6]

This recommendation proposes a relatively major shift in engineering pedagogy. It does so without any evidence that such a shift is desirable or feasible. In addition to pedagogical concerns, personal experience has shown that students will take advantage of this approach. No class of undergraduate engineering students will ever admit to having been taught any mathematical technique. My peers and I were taught partial-fraction expansion, partial derivatives, and Cramer's Rule on three separate occasions during our undergraduate education.

Recommendation 7

> "The students' competency in realistic design and problem solving should be improved by emphasis on project work and modern, computer-based design methods. The encouragement of curriculum innovations should strengthen the teaching of design." [31, Undergraduate Engineering Programs Recommendation 7]

The belief that design is assisted by computer-based methods is unsubstantiated. A number of prominent engineers would in fact take major issue with this assertion [199, 111, for example]. The call for curriculum innovations, while a step in the right direction, ignores the reality of the practice of engineering design education. There have been no rigorous studies on the teaching of engineering design. There is no funding for research into design pedagogy. There are no materials that discuss the broad state of design education. There is no evidence that "encouragement" is intended to cover all of these issues.

Recommendation 8

> "The development of leadership and teamwork skills should be fostered through lectures, case studies and team work which include students from other engineering and non-engineering disciplines." [31, Undergraduate Engineering Programs Recommendation 8]

This recommendation contains only one problematic aspect. As usual there is no evidence that teams involving both engineering and non-engineering students result in a superior learning experience.

Recommendation 9

> "Increased opportunities should be provided to familiarize students with engineering practice through improved work experience programs and mentoring by experienced engineers from industry." [31, Undergraduate Engineering Programs Recommendation 9]

This recommendation is predicated on the belief that the purpose of engineering education is to produce practising engineers. However an alternative view of engineering education has been put forward. Under this view undergraduate engineering is a technologically focused version of the BA. Engineering education focuses on broad technological literacy not on the profession or practice of engineering. An engineering programme that adopts this perspective may not be served by this recommendation.

Recommendation 10

> "Engineering students should be provided with opportunities to develop their competencies in at least one language and culture other than their own at a

level appropriate for engineering practice[1]." [31, Undergraduate Engineering Programs Recommendation 10]

This recommendation has little to criticise. It can be treated as an additional constraint on the existing CEAB complementary studies criteria.

Recommendation 11

> "Increased efforts should be made to develop the communication and teaching skills of new faculty members." [31, Engineering Professoriate Recommendation 1]

This final relevant recommendation can be criticised only from the perspective of implementation.

Beyond an almost complete lack of substantiation this report suffers from not including any form of implementation plan. Beyond identifying responsibilities and recommendations it does not propose any further action. The changes that are described address fundamental issues not only within engineering education but also within the education systems as a whole. Some comprehensive plan is required for these recommendations to be adopted. Given that this report was authored by professional engineers the lack of life cycle planning is appalling.

4.2.3 *Engineering Education in Canadian Universities*

"Engineering Education in Canadian Universities" was released by the Canadian Academy of Engineering (CAE) in August, 1993. The CAE is not strictly an engineering education organization. Its mandate is to use engineering to enhance wealth and well-being of Canada. The CAE membership is composed of professional engineers. While the exact

[1] The position of the Faculty of Engineering at the University of Waterloo on this issue is as follows: "Students who wish to take linguistic and grammar courses must have their choices approved by their home department Associate Chair for Undergraduate Studies and, if approved, students must also be assessed by the language department to determine their facility with the language. Such courses may only be used to satisfy [requirements specific to a program]. "[257]

composition of the membership is not known, it can be assumed that some of its membership are practising engineering educators and that many of its members were trained in Canada. The qualifications of the 11 member task force that produced the report are not known.

The report is 37 pages in length. It includes eight references, one of which is a major work describing engineering education. The three other references that address engineering education take a narrow scope and are referenced by no other major discussion of engineering education. The remaining four references either focus on engineering research or on the engineering profession. The format of the report has a minimum of prose. Instead it consists of a series of bulleted items, the majority of which are one or two sentences in length. The report does not present a conceptual model of engineering.

The report makes 61 recommendations. Of these 20 are considered key. Only these 20 are assigned to a responsible stakeholder. Table 4.3 lists the stakeholders and the number of recommendations they were assigned. The text does not describe how the key recommendations were selected or how the key recommendations were assigned to the stakeholders. As with all of the reports on engineering education the basis for all of the recommendations is supposition and opinion. As shown in subsection 4.2.1, the CEAB and

Stakeholder	**Recommendations**
Engineering Faculties	6
The Engineering Profession in Canada	2
Canadian Industry	5
Universities	2
Governments	3
Canadian Academy of Engineering	2

Table 4.3: Stakeholders identified in *Engineering Education in Canadian Universities*

ABETCC accreditation are closely aligned to the Grinter report. The CEAB criteria also cover some of the recommendations of this CAE report. The matched recommendations are displayed in table 4.4. These matches are curious as the report is probably too recent to have strongly influenced the accreditation criteria. This implies that either the authors of the CAE report were unaware of the accreditation criteria or they did not deem the criteria as sufficient to achieve the desired end. The four recommendations described above were

CAE	**CEAB**
7	2.2.8
8	2.2.4
9	2.2.4
13	2.2.4, 2.2.5

Table 4.4: Correspondence between CAE recommendations and accreditation criteria

omitted from further study. Of the remaining 57 recommendations, eight recommendations were deemed to be within the scope of this thesis. Each of these recommendations will be cited and then discussed.

Recommendation 1

> "Engineering faculties should adopt, as their primary goal, the educational formation of students in preparation for entry to the engineering profession." [28, Recommendation 3]

This recommendation reflects the professional and industrial focus of the CAE. While the report does mention that engineering programmes should play a role in enhancing the technical education of Canadians, it emphasizes in a number of places that engineering education is intended to serve the profession and industry.

Recommendation 2

> "Engineering faculties should ensure that undergraduate engineering programs are broadly based and holistic in scope, including both those concepts which are fundamental to the discipline and those which are basic to closely related disciplines. Specialization of programs at the undergraduate level should be avoided." [28, Recommendation 4]

While the sentiment of this recommendation is reasonable, as usual the devil is in the details. By not describing in any detailed way the degree to which existing programmes are "broadly based" or "holistic" the report provides no guidance to the engineering faculties. The question of what concepts are "fundamental" to engineering has been debated for as long as there have been engineering departments. It would likely be difficult to find an engineering programme that felt that its core programme did not consist of the fundamentals of engineering.

Recommendation 3

> "The curriculum content should be designed to inculcate those basic attributes - concepts, techniques, skills, habits and insights - that are believed to be of lasting value and applicability. Recognizing that the lifetime of most technical information is short, the rationale for the inclusion of specific information content in the curriculum should primarily be its contribution to development of these basic desired attributes." [28, Recommendation 5]

Implementing this recommendation is hampered by a lack of research into how one goes about inculcating things such as "habits" and "insights". Much of the research into general education focuses on techniques and skills with occasional forays into concepts. Designing curriculum content to address these poorly defined, and quite possibly undefinable, attributes requires access to techniques and research that does not exist.

Recommendation 4

> "Engineering faculties should establish and maintain adequate means for obtaining significant and continuing input from engineering practitioners who can reflect the needs of the marketplace." [28, Recommendation 6]

This recommendation in essence calls for tighter ties between engineering education and industry. The report does not address any of the negative consequences of such ties. The University of Waterloo (UW) is unique in Canada in that its ties with industry are mediated not only by the faculty but also by the students. Cooperative education, which is mentioned in this report as a desirable change to engineering education, may have a number of unintended and negative consequences.

Based on personal experience at UW cooperative education has the potential to affect engineering education negatively. One example, which relates to the choice of tool or technique that is taught, occurred in the introductory programming course. For some time this course used a programming language that was designed for teaching. Bowing in part to pressure from students returning from industry, the language was changed to a more common industrial programming language. This language has the unfortunate side effect of requiring significantly more work to accomplish similar results as the original language. While the students have gained some understanding of debugging and of the details of this language they have not been able to learn general programming principles and practices. If the course had been able to switch to a language more suitable for teaching the students may have become better programmers. In this sense recommendation 6 has the potential to overwhelm recommendation 5 in the name of industrial relevance.

Recommendation 5

> "Senior engineering professors who have a broad range of practising experience should be assigned to teach an integrated approach to the fundamental basic subjects in the curriculum." [28, Recommendation 10]

What is not discussed is whether these individuals actually want to teach such courses. Senior professors may prefer to teach subjects more closely aligned with their research and practising experience.

Recommendation 6

> "Professors should give consideration to the increased use of case study materials in the presentation of engineering subjects." [28, Recommendation 14]

The pedagogy of the case study has not yet been studied in detail. Case studies have been shown to have a number of weaknesses. They tend to promote few, and in many cases only one, perspective on the case. They also tend to guide the student in a particular direction. Given that the stated goal of using case studies is to teach students how to deal with open-ended problems the current approach to case studies may not be appropriate.

Recommendation 7

> "The undergraduate program should be designed to develop teamwork and leadership skills through a cooperative learning approach." [28, Recommendation 16]

Again there is no evidence to support the assertion that a cooperative learning approach develops teamwork and leadership skills in all students. From personal experience it is undeniable that this approach does lead to some students taking leadership roles. It also tends to marginalize other students who are not comfortable with this role. While cooperative education does appear on the surface to be a good suggestion further research is required.

Recommendation 8

> "The Canadian Engineering Accreditation Board should place its primary emphasis on criteria which depend on measures of the quality of the teaching staff, the quality of the learning environment and the quality of the attributes, skills and knowledge acquired by the undergraduate engineering students. The requirement for an appropriate mix of information content should be retained but given secondary emphasis." [28, Recommendation 21]

This recommendation fails to discuss the social aspects of accreditation. As discussed in section 3.6 the accreditation bodies have made an effort to be open to different approaches. Keeping track of CEAB content issues is fundamentally a matter of accounting. Software tools are available at no cost to all engineering programmes to assist in this accounting. Programmes that see this accounting as the fundamental aspect of accreditation are making their own value judgements.

This report should be commended for discussing implementation details. Unfortunately given the content of their next report the CAE has not followed through on its plans.

4.2.4 *Evolution of Engineering Education in Canada*

"Evolution of Engineering Education in Canada" was released by the Canadian Academy of Engineering (CAE) in December, 1999. The composition of the task force that authored the report is summarized in table 4.5. At 17 pages, including Executive Summary and

Position	**Count**
Former Deans of Engineering	3
Current Deans of Engineering	3
Academics	3
Corporate	2
Government	1

Table 4.5: Composition of the CAE Task Force

References, the *Evolution of Engineering Education in Canada* is a short document. More alarming are the five references. Of the five, three have almost no relevance to engineering education. One of the three is an unpublished four page meeting summary developed by a student organization. The other two references are to *Engineering Education in Canadian Universities* and *The Future of Engineering Education in Canada*. The report highlights five recommendations. Four of these fall within the scope of this thesis. The discussions within the report also include a number of recommendation-like points. The report acknowledges that it is predicated on the belief that engineering education has to become a broader enterprise.

While the report is always careful not the criticise the CEAB directly, the first two of the four recommendations imply that the CEAB criteria are inadequate.

Recommendation 1

The first of the recommendations calls for broad education, beyond technical studies, to become "a major thrust in engineering education". [29, Recommendation 1] This recommendation at first appears to coincide with the CEAB accreditation criteria that requires that students experience a minimum amount of contact time in arts and humanities subjects. [32, 2.2.5] The discussion of the recommendation clarifies that the CEAB requirement is inadequate.

> "The emphasis given to these 'complementary studies' and also their breadth and effectiveness are now considered to be insufficient to provide the quality of education which is required for many of the roles that engineering graduates are required to undertake." [29, p.6]

No evidence is given to support the assertion that students are not adequately exposed to studies outside of engineering. The report is careful not to criticise engineering educators who have not ensured that these studies are "closely integrated into the approach to engineering problems and designs." The substantive aspects of the rest of the discussion relate to the time constraints imposed by the four year format of engineering programmes. The report repeats the relatively conventional belief that a focus on fundamentals, application, and problem solving can compensate for increased breadth.

This discussion of time constraints includes another common vision of engineering education. In this vision Professional Master's programmes are introduced and it is anticipated that students will pursue postgraduate degree qualifications. This discussion does not make reference to any of the past attempts by the engineering community to promote this regime. Similar visions have been attempted in the past and have met with minimal success. [219]

Recommendation 2

The second recommendation also appears to call into question the adequacy of the CEAB criteria. This recommendation suggests that "Engineering faculties should emphasize the development of the learning skills of their students." [29, Recommendation 2] This recommendation implies that the following CEAB criterion is not being evaluated appropriately.

> "The curriculum must prepare students to learn independently and must appropriately expose them to engineering research and development or other innovative engineering activities." [32, 2.2.9]

The report does not address the implication that this CEAB criterion is inadequate. Instead it mentions, without any evidence, the apparent benefits of project-based engineering education. Given that the chair of the task force was a former Dean of Engineering at McMaster, and that Prof. Don Woods at McMaster is the foremost Canadian authority on Problem-Based Learning, the omission of any evidence is surprising.

Again the report does not discuss the roles of engineering educators in structuring their activities to support the development of learning skills. In fact the report suggests that the role of the engineering instructor may change as this recommendation is implemented. "The role of the instructor can evolve from that of primary provider of information content to that of facilitator, coach and mentor." [29, p.9] The report manages to avoid any discussion of whether engineering educators are prepared for such a change in role.

Recommendation 3

The third recommendation is the first to step away from issues described by the CEAB accreditation criteria. It is also the first to propose, albeit indirectly, that engineering educators require skills and training that many of them do not currently have.

> "Leaders of engineering faculties should ensure that their faculty members have the vision, values and behaviours needed for their evolving role in preparing undergraduate students to function effectively in our rapidly changing world." [29, Recommendation 3]

> "This recommendation calls for recognition by the leaders in our engineering faculties that they are responsible for inculcating the appropriate attitudes, values and skills among engineering faculty members." [29, p.10]

The relationship between faculty members and Chairs/Deans implied by this statement is one that appears not to exist. For example, department chairs at the University of Waterloo can not require that a professor make use of the Teaching Resources and Continuing Education (TRACE) programmes which include group and one-on-one seminars, course planning, and teaching observations. The discussion of faculty teaching abilities continues with what appears to be a contradiction.

> "Engineering professors are normally appointed on the basis of having specialist knowledge in a field within one of the engineering disciplines . . . Given

> the appropriate incentives they will quickly acquire the skills desired for their evolving professorial roles.” [29, p.10]

Having specialized knowledge in an engineering subject and having survived three degrees does not imply that professors have the ability to develop new skills. The report neglects to mention in any detail exactly what these skills are, save an earlier reference to mentoring and facilitation. It also fails to mention how such skills are to be imparted, beyond a simple blanket statement.

> “The achievement of these objectives can be assisted by providing these faculty members with access to specific preparation in teaching and learning pedagogy.” [29, p.11]

Unfortunately there is no equivalent to the 3M Coaching Certificate for university educators. Even in traditional teaching matters such as lecture preparation and assessment there are few resources that address the specific needs of engineering educators. Those books that purport to do so tend to simply rehash standard techniques without customizing them to suit engineering.

The report proposes a blanket solution to many of these issues. Universities must change their hiring and promotion policies. New hires should have industrial experience and all faculty members must have the opportunity to spend time in industry. This solution ignores the demographic reality of a decline in the number of applicants to faculty positions coupled with a rapid decline in numbers due to retirement. Far from being able to select only those applicants with experience in industry and a willingness to teach, many faculties will be fortunate to find sufficient applicants to maintain their faculty complement.

Recommendation 4

The fourth recommendation addresses the popular debate of breadth versus depth.

> “Engineering faculties should participate in providing liberal education opportunities for all university students, and in improving the technological literacy of the general public.” [29, Recommendation 5]

This recommendation is predicated on the unsubstantiated notion that all education in engineering and the liberal arts has become discipline-specific. The proposal is that faculties of engineering should "take the initiative to assist in advancing the technological literacy of university students." No evidence is provided to support the claim that this initiative is needed. If anecdotal evidence is to be believed, the adolescents of today are acquiring significant technological skill merely by living in a technological society. Whether there are benefits to introducing engineering formalisms to such individuals is an open question. Interestingly this section concludes with the statement that "Efforts in this area may well enhance the willingness of the public... to provide adequate resource support for universities."

The report concludes with a high level implementation plan. This plan calls for discussions to take place with a number of groups including the NCDEAS, NSERC, the CCPE, and the CEAB. To date there is no record that any of these discussions have taken place.

4.3 Discussion

Since the major reports are quite similar, the assessment model developed in section 3.2 was applied to the major reports as a group. The results of this assessment are presented in figure 4.2 and described below.

Scale The major reports all purport to discuss engineering education as a whole. They focus primarily on engineering departments and faculties, the engineering profession, and the engineering industry. Accordingly they score a *wider system*. All of the reports are embellished with ancillary discussions about a variety of topics including achieving economic prosperity, and the future of the university.

Type The majority of the reports exhibit multiple writing styles. Some are internally inconsistent about their categories as they transition from observations to conclusions and recommendations. It can be assumed that most of the reports were written by committees composed of educators, professionals, and government representatives. Occasionally the reports fail to include a non-engineering perspective. Accordingly the reports score a

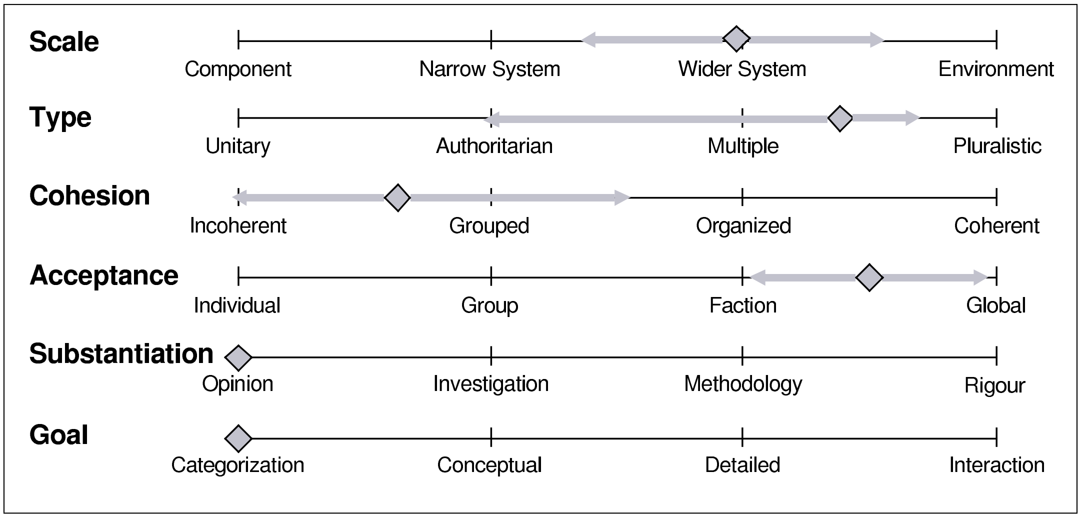

Figure 4.2: Assessment of the major reports

multiple at best.

Cohesion The various reports score quite differently on this scale. However in general the reports score relatively poorly. All of the reports tend to mix scales and types. A single discussion may touch on elements at a variety of levels of detail while simultaneously moving across multiple perspectives. This mixing complicates understanding and probably contributes to difficulties in implementing their recommendations. In general, the older the report the more cohesive its contents. Overall the reports score between *incoherent* and *grouped*.

Acceptance The direct relationship between the major reports and the criteria implies that the reports have been widely accepted.

Substantiation Some tables and graphs are presented in the reports but there are few, if any, links between these tables and the recommendations. The lack of connection between the tables and the recommendations is particularly damning because the tables tend to be the only components of the reports that have references. This lack of substantiation is the biggest flaw within the major reports. Therefore, the reports score an *opinion*.

Goal If any models underlie the various reports they are described only indirectly by the tables of contents. In general the tables of contents, and their associated sections, do have relatively logical, hierarchical structures. This structure is weakened by the lack of cohesion, as discussed earlier, within the different headings. Overall the reports score a *categorization*.

There is a number of significant problems with using the major reports as a source of information about the gaps within engineering education. As discussed above, the major reports suffer from a lack of substantiation. The reports lack comprehensiveness because they do not contain discussion on many aspects of teaching and learning goals and processes. For example the reports on engineering education do not discuss issues such as:

- Are engineering professors qualified to teach teamwork given that their training has emphasized individual performance?
- Given the time it takes to develop curriculum and the 5 years it takes to train an engineering student, how does one design an curriculum that is relevant to industry?
- If companies want engineers who are leaders, why are technical skills the basis when hiring entry-level engineers?

Many of the specific recommendations made regarding curriculum have already been incorporated into the accreditation criteria. The remaining recommendations tend to address broader concerns, such as faculty rewards and relationships with industry. An interesting question is how many and what aspects of these recommendations are limited to engineering. Given that there are no references to reports from outside of engineering education a reasonable conclusion is that engineering educators feel that their issues are unique. This may not be the case.

The recommendations can be categorized at a high level into those that deal with:

- university policies for tenure, promotion, etc.
- attributes and hiring of the professoriate
- relationships with industry
- issues of breadth and core knowledge within the curriculum

- specific teaching techniques topics

The broad discussions of higher education can also be categorized successfully along these lines. The recommendations specific to engineering education come from a unique perspective, with attendant priorities and emphases, but they have much in common with discussions taking place across the wider university community.

The release of *Scholarship Reconsidered* in 1990 signalled a new emphasis on teaching and learning in universities. The subsequent release of *Reinventing Undergraduate Education* by the Boyer Commission on Educating Undergraduates in the Research University has spurned a re-examination of a wide variety of university practices and assumptions. The recommendations of this report bear a striking resemblance to those of more recent recommendations for engineering education.

1. Make Research-Based Learning the Standard
2. Construct an Inquiry-Based Freshman Year
3. Build on the Freshman Foundation
4. Remove Barriers to Interdisciplinary Education
5. Link Communication Skills and Course Work
6. Use Information Technology Creatively
7. Culminate with a Capstone Experience
8. Educate Graduate Students as Apprentice Teachers
9. Change Faculty Reward Systems
10. Cultivate a Sense of Community

The report ignores issues related to curriculum, but there are few other differences between recommendations of this report and of the reports on engineering education.

4.4 Conclusions

All of the major reports reviewed in this chapter present some view of the state of engineering education at the time of their writing. In some ways their discussions are more interesting than those of the accreditation criteria. All of the reports make sweeping generalizations and to discuss the entire engineering education system. Unfortunately what makes them attractive also makes them unsuitable for research. The gaps within, and future directions for, engineering education are based on nothing more than supposition and opinion. Little wonder then that the reports have been identifying the same weaknesses and suggesting the same remedies for almost 50 years.

Chapter 5

An attempt to fill the gaps

This chapter details the design and evolution of a contemporary engineering programme[1]. This programme is unique in a number of ways. The university in which it exists was founded in 1957, two years after the release of the Grinter report. The design of the programme was completed between 1967 and 1969, three years after the formation of the Canadian Engineering Accreditation Board. Simply by virtue of timing the Department was forced to address issues with, and changes to, engineering education. Moreover both the university and the department were founded with the explicit goal of addressing particular perceived deficiencies in engineering education. These deficiencies are similar to the gaps identified in chapter 4. This examination of the design and evolution of the department serves as a guide for others who are trying to address the gaps in engineering education.

The examination begins with an overview of the department. This overview is based on promotional and reflexive materials produced within the department. A narrative history follows the overview. This narrative conveys the history of the department as it is known by the majority of its members. The next section discusses the sources that were consulted while documenting the design and evolution of the department. In keeping with the tenets of chapter 2 the environment present during the design and implementation of the department is then discussed.

[1]Portions of this chapter are an expanded and enhanced version of the paper presented at the 2000 conference of the International Society for the Systems Sciences (ISSS). [119]

The chapter then turns to a detailed discussion of the design and evolution of the department. This discussion follows an engineering approach in two ways. First it treats the department as the result of a design exercise[2]. This allows aspects of the engineering design process to be used to organize the analysis. Of particular interest are the problems being addressed and the constraints, and criteria that apply to the design. These aspects are augmented with a discussion of the design process used and of the evolution of the department since its formation. The second use of an engineering approach is through the application of the model developed in section 3.2. This model is used to frame the analysis.

The chapter concludes with a discussion of the relevance of the department's history to contemporary engineering education. A number of current and proposed initiatives to reform or create new engineering programmes are described. These initiatives are shown to follow a similar approach to that taken by the Systems Design department. The difference is that the department has had 30 years in which to experience the positive and negative consequences of its decisions.

5.1 A case study: The Department of Systems Design Engineering

5.1.1 Overview

> "Systems Design Engineering is the study of complex systems for the purposes of analysis, simulation, optimization and ultimately design." [233]

> "Our primary mission is to provide our students with the best possible education to enable them to become wise and knowledgeable leaders in Canadian industry, government, academia, and other areas of society." [234]

[2]The department may in fact have been the result of an accidental confluence of individuals and resources. Regardless of the historical reality of the situation, as Parnas describes in *A Rational Design Process: How and Why to Fake It* there is always value in documenting a design process, regardless of whether one was followed. [197]

> "Systems design engineering is a relatively new branch of engineering, and integrates selected material from other programs within the Faculty of Engineering that have relevance and applicability in most systems contexts...
>
> Systems design engineering is multi-disciplinary and works at many levels of abstraction. From analysing the signal processing characteristics of a single nerve cell; to macroscopic human-machine systems involving psychological factors; to broad high-level studies in society, technology, and values. The systems design engineer is a most adaptable individual, and among the most capable people in society.
>
> Finally, systems design engineering prepares the student for leadership in a complex technological society that requires interdisciplinary thinking capability to meet future needs for complex, balanced decision-making."

Over the last 30 years the Department of Systems Design Engineering (SYDE) at the University of Waterloo (UW) has offered students the opportunity to pursue studies in engineering that incorporate design, transdisciplinary techniques, and systems thinking. As an example of the successful merging of these concepts, the department is in many ways unique.

5.1.2 Narrative history

> "From a start with one faculty member in Mechanical Engineering the work has grown to a small group in the Mechanical Department, then to a small department concentrating on graduate work and finally to the present full department. During that period ideas have changed and matured. The concept of systems and systems theory has been chosen as the central integrator of desparate [sic] approaches to design. Particular curricular and pedagogical approaches to the education of Systems Design Students have been tried, changed and evolved. Students and faculty have argued about, wrestled with, and reacted to the philosophical and empirical problems of defining and developing a new engineering discipline. Perhaps the only consistent objective throughout this growth period takes the form of a statement of faith rather than fact. It

> is the conviction, by those involved, that we can produce an educational environment which will prepare students to creatively solve technological problems in a manner that makes technology the servant of the human spirit." [237, attributed to George Soulis]

In many ways there is no usual narrative. The average student or faculty member in Systems Design has no information describing the origins of the department. Digging deeper reveals the fairly brief and fragmented oral history presented here.

In the late 1950s George Soulis approached Doug Wright, the Dean of Engineering at Waterloo. George had worked on a number of design projects abroad and on his return to Canada was dismayed about the lack of formal education in design. He commented on this matter to Dr. Wright. Dr. Wright then asked George to try and help fix the problem. George subsequently went to Germany for a year to develop his design skills.

At the same time, a new professor of Electrical Engineering named H. K. Kesavan arrived at the University of Waterloo. Dr. Kesavan was pursuing a new branch of science known as Physical Systems Theory and quickly developed a strong reputation at the University. He returned to his native India in 1963 to start the Indian Institute of Technology at Kanpur.

When he returned from his trip, George, assisted by V. K. Handa and Peter Roe, both of whom had been Dr. Kesavan's students, developed a mandatory course in first year engineering called "GE11 Engineering Synthesis".

Shortly thereafter the Government of Canada released tenders to design the pavilions for Expo '67. George formed the Institute of Design at the University of Waterloo to bid on these tenders. The members of the Institute came from a variety of backgrounds including medicine, film making, and engineering. The Government commissioned the Institute to design a number of buildings and exhibits for the exposition. The commission included rather substantial funds. These funds allowed the department to function without the income that an undergraduate programme would otherwise provide. To allow the members of the Institute to teach, a Department of Design was created within the Faculty of Engineering.

Based on the successes of Expo '67 the department was offered the opportunity to design the Ontario Science Centre. Its members declined, preferring to devote their energies to developing an undergraduate programme. While designing the Expo '67 buildings the Department of Design had developed significant skills in architecture and building design. The plan within the Department of Design was to create a new department of Environmental Design that would merge the newly acquired skills in architecture with the pre-existing skills in design. To add another dimension to the department, George travelled to India to recruit Dr. Kesavan. Together with a recent graduate of the Department of Electrical Engineering named Peter Roe, George and Dr. Kesavan developed a new expansion plan. The plan called for a new department that would merge the study of design with the study of physical, human, and socio-economic systems.

Unfortunately the plan was derailed when the President of the University chose to create a department of Architecture as a part of the Faculty of Environmental Studies. Having been split in two, and still needing to create an undergraduate programme, the Department of Design needed to develop a new plan. The result was the Department of Systems Design Engineering.

5.1.3 Terminology

The definitions given in table 5.1 are those which were documented by the Department of Systems Design Engineering. The degree to which these definitions are known or used by members of the department or other organizations is not known.

5.1.4 Sources

The sources that contributed to this analysis can be divided into two broad categories. Formal sources are those that exist in tangible forms and informal sources are those that do not. Other researchers can find the formal sources in an unaltered form. The informal sources are the result of personal experience, conversation, and tradition and are impossible to duplicate.

5.1.4.1 Formal Sources

The formal sources used in this discussion include:

Term	Definition
System	A system can be defined in its most general form as a collection or assemblage of items united by some form of interaction or interdependence. [233]
System Theory	The department has not documented a definition of this term. Current discussions of system theory within the department focus on Graph Theoretic Modelling, a technique whose genesis was in the physical systems domain.
Design	The department has not documented a formal definition of the term 'design'.
Interdisciplinary	The term "interdisciplinary" pertains to the situation in which diverse material from various academic disciplines is presented to the student within the frames of reference of the disciplines concerned. [159]
Transdisciplinary	The term "transdisciplinary" pertains to the situation in which attempts are made to break down the barriers imposed by disciplinary frames of reference. [159]

Table 5.1: Definitions used internally by Systems Design Engineering

- minutes of various council and administrative meetings [75, 78, 79, 80, 76];
- undergraduate and graduate calendars, brochures, and course outlines [73, 68, 74, 77, 71, 72, 41, 171];
- student yearbooks [237, 238, 239, 240, 271];
- workshop and design symposia [225, 209, 175, 212, 45, 40, 70]; and,
- journal articles, conference papers, and both published and unpublished internal documents. [208, 160, 89, 213, 159, 134, 10, 6, 152, 7, 50, 132, 8, 128, 9]

For some formal sources, it is impossible to provide a meaningful reference. Readers who are interested in obtaining copies of any these materials should contact the author.

The primary advantage provided by formal sources is that they are more rigorous. By virtue of being in written form they tend to be better thought out and include references to supporting evidence. Similarly they all provide some guarantee of accuracy by providing the identity of the individual who compiled the document. However, the formal sources tend to present a very sterile view of the department. They are predominantly descriptive of the department itself, as opposed to describing the process by which the department was formed. By adopting this approach they ignore the complex web of personal and organizational relationships that guided the department's design. The creation of Systems Design crossed a number of organizational and political boundaries, therefore acknowledging this web of relationships is important. The formal sources also tend to record only the department's successes and the paths that were actually followed. Similarly there is usually no mention of the political exigencies that cause certain decisions to be made.

The University Calendars and student yearbooks require further discussion. The contents of the Calendars are established approximately one year before they are distributed. As a result they often contain information that is no longer correct. For example, sometimes courses listed in the Calendar are no longer offered. Therefore the Calendars cannot be used to date events accurately or as a complete record of any changes that took place. The student yearbooks are another formal source of information in which authors are typically identified. However, these documents are characterized by colourful content and do not represent an attempt to present an unbiased perspective. Nevertheless they are one of the very few sources that describe the students' perspectives.

5.1.4.2 Informal Sources

Personal experience, buttressed by discussions and interviews with many of the original members of the department, have also influenced this discussion. The three founders, and many of the original faculty members, are still alive and active within the department. Some of these individuals described the design and evolution of the department.

The informal sources could provide information that the formal sources could not. Where the formal sources focused on the *what* of the design, the interviewees focused on the *why*.

The informal sources also had a number of disadvantages. Foremost among these was that it was impossible to corroborate many of the stories and anecdotes. Given that each source had a unique perspective and focused on particular details and aspects of the design there was little, if any possibility for corroboration.

Future research into the design and evolution of Systems Design Engineering should incorporate a formal, qualitative human research protocol. Such a protocol was not followed in this instance for a number of reasons. First, the author had neither experience nor training in human research. Neither was obtainable in the available time. Second, this thesis is being developed for academic credit within the Department of Systems Design Engineering. It is extremely unlikely that the author, or the department, would be able to maintain the critical distance required for such research. It would be both interesting and valuable for the Department of Systems Design Engineering to become the subject of a formal anthropological investigation by a third party investigator.

5.1.5 Context

The related concepts of context and environment have been discussed in chapter 2 and table 3.1. This section provides an overview of the environment within which Systems Design Engineering was formed and has evolved.

The environment can be examined from a number of different perspectives. For example the department exists within physical (buildings), bureaucratic (organization charts), legal (engineering act, universities act), political, and emotional spaces. Given the formal sources that inform the discussion a bureaucratic perspective was chosen. The different facets of the environment, and the approximate relationships between them, are described in figure 5.1. Most of the elements in figure 5.1 are either singular or grouped bureaucratic entities. The "Wider History" element acts as a catchall item for facts or trends that are not a part of any other element and do not fall within the bureaucratic arrangement.

Figure 5.1 implies a strict separation between the entities that exists only within this perspective. From other perspectives, for example human resources, this separation is artificial. For example, members of the Faculty of Engineering may also serve in the administration of the University of Waterloo and be members of the Engineering Profession. A common belief is that an individual can wear several "hats" and that when switching hats will undergo a complete change of perspective and allegiance. From personal experience this is not always the case, especially in small, dynamic organizations such as UW circa 1955.

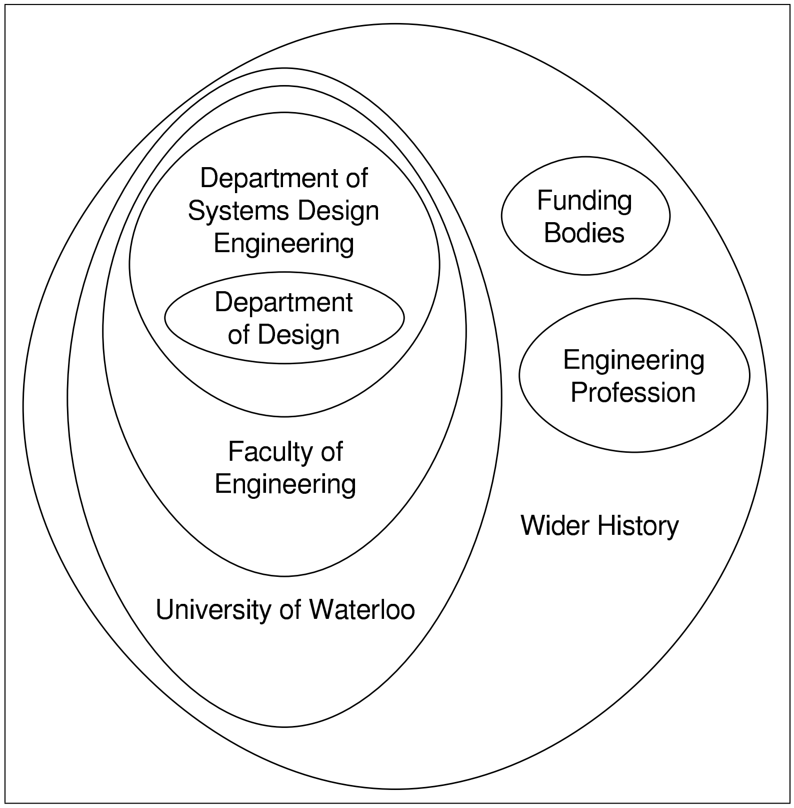

Figure 5.1: Idealized representation of the Systems Design Engineering context

The format of figure 5.1 implies that the department's environment was a strict hierarchy. This is an artefact of having chosen bureaucratic entities to partition the environment. This structure implies that the effects of larger entities, for example the University of Waterloo, would be transmitted exclusively through contained entities, in this example the Faculty of Engineering. In reality this is not the case. A more accurate depiction of the relationships is presented in figure 5.2. In this representation each element in the environment affects all of the others. For example individual faculty members can interact directly with the University or with funding agencies without the intermediation of the Department. While figure 5.2 may be more accurate it provides insufficient structure to usefully frame discussion.

The following sections describe many of the components that comprise the environment.

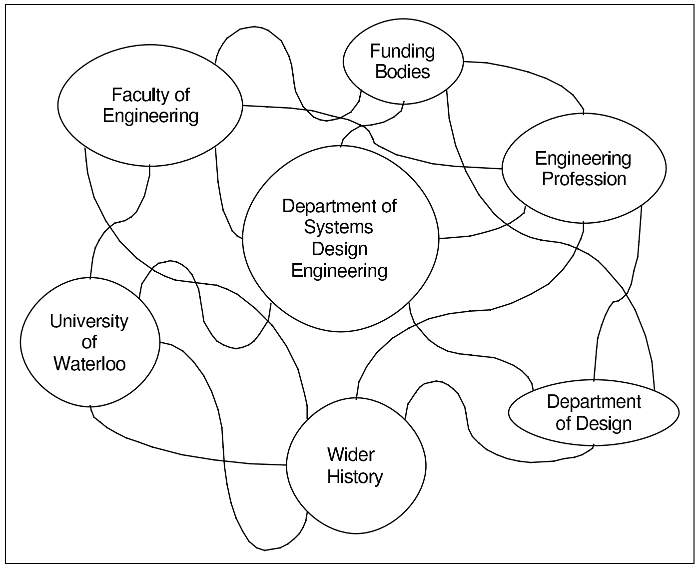

Figure 5.2: Accurate representation of the Systems Design Engineering context

Two, “wider history” and “engineering profession” are described in chapters 3 and 4. Given that this discussion focuses primarily on the design and implementation of the department the descriptions focus on the period from 1965 to 1970. Significant changes or events that have taken place during the years following 1970 are also included to support the discussion of the department’s evolution. The discussion is ordered most to least enclosing.

5.1.5.1 Funding Groups

Funding for engineering research in Canada has historically come from two main sources. The primary source of funding is the Natural Sciences and Engineering Research Council (NSERC). Prior to 1978, when it fathered NSERC, the National Research Council (NRC) oversaw research funding in Canada. NSERC provides approximately one third of the research funding to Canadian universities. [188]

The majority of the current NSERC Grant Selection Committees (GSCs) focus on particular discipline or sub-disciplines. Examples of GSC areas include Condensed Matter Physics and Civil Engineering. Only one GSC, a member of the Life Sciences and Interdisciplinary sector named Interdisciplinary, deals explicitly with proposals that cross fields. Based on the projects that received funding in 1999 the definition of interdisciplinary used by the GSC is not the same as the definition presented in table 5.1. [190] There are no funding groups that go beyond interdisciplinary topics to explicitly address transdisciplinary research. GSCs with broad mandates, such as General Physics and Pure & Applied Mathematics, might fund some transdisciplinary research but they do not seek out such projects.

During a self-assessment performed in 1998 NSERC acknowledged that interdisciplinary research was an area in need of NSERC support.

> "Very few of the submissions contained specific proposals for interdisciplinary research with other groups. The committee was disappointed that many obvious opportunities had not been pursued. It concluded that the nature of the Reallocations process itself (a competition among disciplines for funds) may have led the disciplines to look inward and 'circle the wagons'." [187]

NSERC reacted to this assessment by developing new guidelines for interdisciplinary grant applications.

> "NSERC recognizes the growing importance of interdisciplinary and multidisciplinary research, especially in new and emerging areas of science and engineering. Although the current structure of the GSCs is discipline-based, this need not be a barrier to addressing interdisciplinary or multidisciplinary issues in the Reallocations Exercise. Two or more Steering Committees may decide to collaborate on a joint proposal for funding..." [191]

These guidelines propose that interdisciplinary researchers appeal to all of the applicable GSCs. In adopting this policy NSERC is ignoring many of the difficulties experienced by interdisciplinary researchers. Informal discussions with such researchers reveal that they may experience scepticism, if not outright enmity, from discipline-specific researchers. The NSERC policy requires that interdisciplinary researchers convince multiple groups, all of whom are likely to be sceptical, of the value of their proposals.

Based on its response to the issue of interdisciplinary research NSERC shows no signs of reforming or making significant changes to its GSC-centric structure. The process by which a new GSC is created is not formally documented in a publicly accessible space. The process is based on the perceptions of those who administer NSERC. Once a community of researchers who all focus on a particular area has developed on its own to the point where it has been noticed, NSERC will consider either expanding the mandate of an existing GSC to cover the new area, or it will create a new GSC for that community. NSERC's mandate does not include creating GSCs with the express purpose of promoting a particular research area. [22]

Where NSERC will take a proactive role in the promotion of a new area is through the development of research chairs. The most recent set of research chairs is in the area of design.

> "One of the major gaps in Canada's innovation system is the shortage of people with the skills and knowledge to make innovation happen. Specifically we lack design engineers. Design engineers in particular are the enablers of innovation and if we want to become more successful in innovation, we have to educate and train more of them." [189]

The chairs in design are sufficiently new that no results, other than the identities of the winners, have been announced.

5.1.5.2 University of Waterloo

The University of Waterloo (UW) is one of Canada newest universities. Formed in 1957, it has excelled and was ranked the best comprehensive university in Canada from 1992 through 1998. [256] The University was founded on the pillars of cooperative education, computing, open access, and technical research.

The political climate in which the University gestated was one where funding was available and where innovation was encouraged. To encourage innovation the University adopted a decentralized model where Deans and department Chairs were given significant latitude to implement the programmes and ideas that they saw fit. The atmosphere of the early years can be likened to a car travelling quickly down a bumpy road; if you travel fast enough you stop feeling the bumps.

It took significant funding cuts from the Provincial government in the late 1980s and 1990s to change this attitude. The current situation is one where innovation remains valued but where resources are stretched so thinly that in many cases it is not possible. As the pace of change has slowed and the reputation of the University has grown the culture of the University has become more conservative. Where mistakes could once be handled by simply pressing forward, the current attitude is one where mistakes can not be allowed to happen. Similarly there is a push for centralization of control to reduce duplication and to increase accountability.

The University of Waterloo is best known for its cooperative programme. While the programme is particularly strong in Mathematics, Computer Science, and Engineering, in principle any student can participate. The cooperative programme at UW is tightly integrated into the undergraduate curriculum. Students in the programme interleave four-month school terms with four-month cooperative placements. This arrangement is different from the internship programmes at other universities where the work experience is lumped into a 12 or 16 month span. In technical fields such as engineering or computer science the percentage of students who find work placements per term is usually above 90%.

The theoretical benefits of including cooperative education are many. From the University's perspective, curriculum can focus on theoretical content while the cooperative work terms provide practical experience. Cooperative education also helps to promote strong linkages between academia and industry. From the student perspective, cooperative education can help to reduce student debt, provide a welcome break from studies, validate that a course of study is of interest, and provide resume material. The reality of cooperative education is somewhat different.

The separation of theoretical and practical aspects of education is generally not possible. One example of this phenomenon is the choice of language in introductory programming courses. The need to maintain high cooperative placement rates may pressure instructors to teach the computer language preferred by employers instead of a language that provides better learning opportunities. Where industry was supposed to provide the practical training and the University the theory, the reality is that the University is pressured to provide both.

The interleaving of cooperative placements and academic terms also has negative effects on education. Students begin applying for the next work term's jobs in the third week of term. Interviews begin shortly thereafter and may conflict with lectures, tutorials, or exams. The fact that the students alternate academic and cooperative terms limits the amount of material that can be covered in a course and limits courses to the four month terms.

5.1.5.3 Faculty of Engineering

The Faculty of Engineering began offering degree programs in 1957[3]. The approach to engineering education taken by the Faculty evolved quickly during its first five years. The mandatory humanities courses and the overall orientation of the degrees changed the most. When the Faculty of Engineering started it did not have access to courses taught in the Faculty of Arts. The Faculty required that each student take a minimum of four humanities course, so it developed and ran courses in the humanities specifically for its students. The original set of courses, as organized into groups by the Faculty, is listed in table 5.2. Students were required to take a specified number of courses in each division. In 1959-

Division A	**Division B**	**Division C**
• Economics • Political Science • History • Geography	• Philosophy • Psychology • Sociology • Principles of Biology	• Scientific Russian • Scientific German • Foreign Language • English Literature

Table 5.2: Original humanities courses and divisions

60 the divisions were dropped in favour of a single list of subject areas. In 1961-62, as the University expanded its course offerings in the arts and the humanities through the Faculty of Arts, the list of humanities courses was dropped from the Faculty description. The requirement that students take humanities courses remained and was enforced through

[3]What became the Faculty of Engineering at the University of Waterloo admitted its first students to a degree programme in 1957. The first undergraduate engineering degrees were conferred in 1962. The first graduate students were admitted in 1960.

mandatory electives scattered throughout the curriculum. For example in 1961-62 a student in Year I had to choose between English Literature, History, or Philosophy.

In 1978-79 a discussion of the electives in the humanities was restored to the Faculty of Engineering description. Based on a CEAB requirement for "...a minimum of one-half year of appropriate humanities and social sciences..." [32], the Faculty developed the General Studies Programme in Engineering. The number of arts and humanities courses was sufficiently large and the topics covered sufficiently broad, that electives needed to be separated into divisions and students were required to take a minimum number from each division.

The most dramatic change in the nature of the engineering curriculum at UW took place in 1961-62[4], five years after the launch of Sputnik I. This year saw the removal of the programme in Engineering Physics and the rise of "scientific engineering".

> "Engineering Physics programmes, in which studies in engineering are associated with advanced study in Mathematics and Pure Science are thus available, in effect, in every major field, and supplant previous separate courses in Engineering Physics.
>
> Since the Faculty of Engineering is primarily oriented towards a modern scientific approach to engineering, students interested in Engineering Physics can register in any one of the major engineering programmes and pursue a suitable course of study..." [248]

This change in orientation towards science and away from more traditional experiential methods of engineering education aligns with the changes in the engineering profession at this time. By requiring that all engineering students be members of the cooperative programme the Faculty was able to merge theory with industrial practice, in effect producing students schooled in both the modern scientific approach and the traditional apprenticeship and experiential approach.

> "The preparation for an engineering career includes both formal academic studies at a university and intensive training in the practice of engineering. A similar pattern is to be found in preparation for careers in medicine or law, and is

[4]This change was recorded in the 1962-63 calendar.

characteristic of any development of professional competence. The Co-operative Engineering Course at the University of Waterloo provides a completely integrated pattern of academic study and industrial experience in various phases of engineering...the co-operative course brings a student into direct contact with the engineering profession and exposes him to problems typical of those encountered in practice." [250]

From the beginning the Faculty has allowed students significant flexibility in their curriculum. Flexibility for students was promoted through the use of elective courses.

> "The curriculum for each of the four basic programs combines required 'core' subjects essential to the field, and 'elective' subjects permitting considerable diversity in individual programmes of study. ...The optional programmes that are made available...should not be construed as specialization, but are rather intended to foster independent study and maturity of learning by permitting special undergraduate activity in subject areas which hold maximum interest." [250]

The Faculty changed the option programme in 1986-87 through the introduction of "designated options." These options were integrated into the programmes and successful completion of one or more options was recorded on student transcripts. Prior to this change, the faculty made explicit mention of a single, informal option in engineering physics. This informal option was removed in the 1976-77 academic year. It was later revived as the Option in Physics when the designated options were introduced.

One of the cornerstones of the Faculty of Engineering was its early focus on engineering research. In keeping with this focus, UW was among the first Canadian universities to offer undergraduate engineering degrees that focused on research. Between 1977 and 1978 the Faculty of Engineering developed the Combined Bachelor's-Master's programme. The programme was approved in 1978 and first advertised in the University Calendar in 1982. The primary goal of the programme was to further support engineering research.

> "The [Combined Bachelor's-Master's] programme is a response to a number of needs among which are:

- recognition of outstanding students and provision of academic enrichment for them;
- provision of an introduction to the postgraduate milieu for good undergraduate students who might otherwise overlook the opportunity of graduate studies;
- provision of a reasonably firm time horizon for the completion of the MASc programme.

The programme provides a mechanism for the institution of a quicker route to the MASc degree, for outstanding students, on a Faculty-wide basis." [254]

The Combined Bachelor's-Master's programme also offers the departments two ancillary benefits. First, it simplifies recruitment and admissions. Students in the programme can follow an abbreviated admissions process compared to regular applicants. The department can engage in less active recruitment beyond its own borders. Given the importance of attracting Master's and Ph.D. students, the Combined programme offers a good return on investment. The second advantage of the programme is that it allows for continuity within the programme. Many graduate students act as teaching assistants (TAs) in undergraduate courses. TAs who experienced the undergraduate programme firsthand are familiar with not only the idiosyncrasies of particular equipment or procedures but can help explain to students the rationale behind the curriculum. The value to the departments of TAs who know the details of their undergraduate programme cannot be overestimated.

In terms of student workload, the Faculty has twice suggested to its constituent departments that they reduce their course loads. The first reduction, from seven courses a term to six, was generally implemented in the 1981-82 academic year. General implementation of the second suggested reduction, from six courses to five, took place during the 1990-91 academic year. According to faculty members present during the transitions, the stated rationale for the changes was to reduce the cognitive shifting required of the students throughout the term.

More recently the Faculty has begun to investigate interdisciplinary opportunities. In 1995-96 two programmes in Environmental Engineering were created. One programme is affiliated with the department of Chemical Engineering, the other with the department of Civil Engineering. Both Environmental Engineering programmes work with their host departments but maintain distinct identities. Many of the designated options, such as the Option in Management Science or in Mechatronics, also promote interdisciplinary activities. The Faculty is also moving towards interdisciplinary partnerships with other faculties. For example new programme in Software Engineering is a joint venture between the faculties of Engineering and Mathematics.

Prior to the formation of the Department of Systems Design, starting in 1964, all undergraduate engineering students at Waterloo were taught design through a single course, *General Engineering (GE) 11 Engineering Synthesis*.

> "GE11 Engineering Synthesis Principles of problem statement, analysis, and concept creation in the design process. Discussion of planning, the flow of information, physical, economic and financial feasibility, and concept selection as related to project design. Discussion of social and economic conditions affecting value and utility, and their relationship with the design process in the solution of engineering problems. The application of simulation, modelling and optimization to the above: three term projects." [251]

This course was offered by the Department of Design and was a common core course in the first the 1A and then the 1B academic term. The course was held as a single class of several hundred students from all engineering disciplines. Students were required to take the common GE11 until the 1977-78 academic year when it fragmented into discipline-specific variants. These variants were customized by the individual engineering departments with varying levels of design content.

The faculty members in the Department of Design felt that design was a skill best taught through experience. The term projects in GE11 provided the student with opportunities to experience design issues first-hand under the tutelage of an experienced faculty member or senior teaching assistant. When the Department of Systems Design was formed it incorporated these beliefs regarding design education into the Workshop series.

Engineering undergraduates were introduced to the concept of a system in a second course offered by the Department of Design. Unlike GE11, this course was not made a part of the general engineering core.

> "GE12 Introduction to Engineering Systems Introduction to the basic methods

of analysis through mathematical models for components and processes. Systematic formulations of terminal representations of system equations or linear systems, utilizing terminal and system graph concepts in conjunction with matrix notation. Solution, through Laplace transforms and by computer methods. Examples are drawn from the various engineering disciplines." [251]

In keeping with the engineering orientation of the course, GE12 dealt exclusively with hard systems techniques. However it represented the realization that general analysis techniques were valuable and paved the way for the creation of the Department of Systems Design to provide further opportunities for students to explore systems concepts.

The use of systems concepts in engineering, both broadly and at the University of Waterloo, has decreased since the 1970s. Based on an examination of University of Waterloo undergraduate calendars, engineering courses devoted to systems concepts have been concentrating in the Department of Systems Design Engineering. Overall the number of such courses has also dropped. More broadly the use of systems concepts in introductory engineering texts has also been declining. A number of such texts published in the 1970s included explicit discussions of the transdisciplinary nature of hard systems theories. [125, 17] These texts showed how problems in chemical, electrical, hydraulic, and mechanical engineering could be solved using the common systems framework. By the 1990s introductory engineering texts had ceased to discuss such approaches to engineering problem solving. [141, 24]

5.1.5.4 Institute and Department of Design

"The Department of Design was formed at Waterloo in 1965. Since that time it has received international recognition for its graduate programmes, research activities, and design projects. The most widely known of these many efforts include the department's design and research work for Expo '67, Canada's Centennial World Exhibition, its sponsorship of three international design conferences, its research into design morphology, and its development of creative teaching methods from the point of view of pedagogy, content, and advanced hardware facilities." [233]

1965-66 saw the creation of two related design organizations. The Department of Design was created within UW to enhance the design component of the common engineering curriculum and to research engineering design. The independent Institute of Design was formed to design and build pavilions and exhibits for Expo '67. While organizationally separate, the two organizations shared the same membership and facilities.

> "The Institute of Design is a financially independent and working Institute that contributes to the development of formal academic programmes while not acting as a teaching organization. Through the Institute of Design the student has the opportunity to work and contact with a varied group of professional consultants and full-time Institute staff that have backgrounds in the areas of Product Design; Psychology; Fine Arts; Films; Civil, Electrical and Mechanical Engineering; and Graphic Design." [249]

The Department of Design offered courses at both undergraduate and graduate level. It also ran design seminars and workshops for faculty and students. Graduate students were offered a programme that led to the degree of Master of Applied Science in Environmental Design. Graduate courses offered by the Department included *Design Heuristics*, *Creative Synthesis in Design*, *Design Morphology and Organization*, and *Planning of Innovative Design Processes*.

From the beginning the department was oriented towards interdisciplinary activities. By virtue of the need to construct pavilions for Expo '67 the early work of the department focused on architecture. Starting from the work of Alexander, the department developed an approach called Environmental Design. [1] As described by the department, this approach focused on the relationship between individuals and their physical environment.

> "The programme is unique in that it brings together various academic disciplines, research and working professional designers to achieve educational balance between the laboratory and the development of theory and methodology. The graduate programme has been designed to prepare the student to work in the ever-increasing complexity of the Human Physical Environment and handle multi-factor design problems with intelligence, experience and skill." [249]

Coincident with the development of the Expo '67 pavilions, three faculty members of the department co-wrote "The Discipline of Design". Published in 1967, its authors maintain that this work was among the first to treat the engineering design process as a subject of investigation and research. A citation and literature review of other design resources provides partial confirmation that this book was indeed among the first to focus on engineering design in this fashion. [91, 269, 263, 144, 84, 95, 93, 24]

> "In the past, design has often been studied in a fragmentary fashion. There has been a tendency merely to examine the actions, methods, and procedures associated with particular classes of object. Therefore machine design, architectural design, etc. are all regarded as legitimate fields of endeavour in their own right. This book suggests that the methods and procedures used in design can be studied as a unified subject which is not dependent on the object being designed." [210]

After Expo '67 the department began to plan its future. Three paths of evolution were pursued. The first was the development of a programme in Architecture within the department. The second was the initiation of a PhD programme. The third was the creation of an undergraduate programme. While the department was investigating its options, the University created a new Faculty of Environmental Studies. The actual path taken by the department is discussed briefly in Kesavan et al. [159]

> "...Engineering Faculty Council at it meeting of October 2, 1968, approved motions to establish a School of Environmental Systems Design and to inaugurate a new undergraduate course in Systems Design to begin in the Fall semester of 1969. The course was to be administered by the proposed school and to be run in conjunction with the existing program in Environmental Studies. Subsequent events led to the separation of the architectural group from the Faculty of Engineering, and have in consequence provided the Department of Design with a new opportunity to re-assess its development."

The rationale behind choosing to create an undergraduate programme has not been documented. Possible reasons include developing wider interest in the notions of systems and design, obtaining funding from the Provincial government as the monies from Expo '67 had been spent, or the establishment of a feeder programme to grow graduate enrolment.

> "There has already been ample discussion of the need for an undergraduate program that deals with the attributes of physical, human, and socio-economic systems. It is therefore not necessary to dwell at length on this topic." [159]

In November, 1968, the Engineering Faculty Council approved the creation of the Department of Systems Design. The Department and Institute of Design were subsumed into this new entity. The early assets of the department of System Design were the skills of its members and a reputation for excellence in design and design education.

5.1.6 Design problem

The overall problem faced by the founders of Systems Design Engineering was simple: "Design an undergraduate component for the Department of Design." More interesting are the constraints and criteria that guided the design process. Some of the criteria were defined explicitly in the proposal documents. [159] The majority of the criteria have been inferred from the actual design of the programme.

In keeping with the engineering approach to analysing engineering education the constraints and criteria are partitioned into the components of the model presented in figure 3.2.

5.1.6.1 Inputs

Faculty

- All of the members of the former Department of Design must be involved
- All of the founding members must be able to pursue their individual interests

Emerging adults[5]

- Students must be given the maximum possible flexibility in designing their individual programmes
- Students must be able to defer choosing a speciality for as long as possible
- Students should be able and encouraged to take ownership of their education. This includes choices within particular courses, for example project topics, as well as choices that affect their path through the programme
- Students should expect to be responsible for planning and auditing their programme.
- Students must be encouraged to pursue graduate studies

5.1.6.2 Parameters

Infrastructure

- Use only the infrastructure currently available

Goals

- "The ensuing programme is founded on the belief that the need for broadly educated individuals who are capable of handling transdisciplinary problems can be met uniquely in a program which combines the philosophy of design with the discipline of system theory." [159]
- The department, consisting of the faculty, staff, and students, should see itself as an integrated group with a shared purpose. Among the students the intent is to avoid the formation of cliques and to promote collaboration.

Processes

- Administrative compatibility must be maintained with other engineering programmes
- The programme must be compatible with future trends in engineering education

[5]When individuals apply to the programme they are considered emerging adults. Once within the programme they are considered students.

- The programme must generate income comparable to that of other engineering programmes
- The department should be able to constantly develop and deploy new and innovative ideas in engineering pedagogy
- Material from disparate courses should be integrated
- Problems should cover material from disparate courses
- Correspondences and disparities between different approaches and techniques should be discussed
- There should be a balance between theory and application. This balance should exist whether or not cooperative education is involved. Examples in class should reflect the practice of engineering, as opposed to the practice of textbook solutions.
- Students should be able to experiment and explore different paths through the programme

Content

- Students should be taught design explicitly in the classroom. Design should be taught both as a theoretical topic and as a practical exercise. All students should have to grapple with the design process.
- System Theory
- ...physical, human, and socio-economic systems. [159]
- Students should be aware of the theory and have been exposed to the practice of group work.
- Students should be able to communicate in a variety of forms to a widely varying audience. The Systems Design Engineer should be comfortable communicating with experts in technical disciplines as well as management and the public. Forms of communication include diagrams and drawings, technical and non-technical reports, and oral presentations.

Structures

- As with processes, compatibility must be maintained with other engineering programmes.

5.1.6.3 Transformation

No constraints or criteria were explicitly placed on this component.

5.1.6.4 Outputs

- Students must be marketable through the cooperative education system
- Students should be taught that engineering is an exercise in satisficing[6]. Answers to engineering problems depend on context. In some cases, for example when solving a calculus problem, there is a single, prescribed answer. In contrast there may be multiple solutions to open-ended design problems. Students should develop an awareness of the need for judgement, and to a lesser degree intuition, when developing engineering solutions. This skill is usually not taught in scientific engineering where there are the correct answers to the problems presented in the textbook.

5.1.7 Design processes, invariants, and external players

The founders of the department had backgrounds in both "hard" and "soft" systems areas. To ensure a balance between these areas, the development team adopted a particular structure. The "hard" systems members were primarily responsible for proposing ideas for the new programme. The "soft" systems members were then given the opportunity to veto or modify the original proposals. By virtue of the Faculty context developing solutions that met the "hard" systems criteria was fairly straightforward. By forcing the "hard" systems members to meet the needs of the "soft" systems members, a greater number of possible solutions were generated.

The Dean of Engineering was one of the most ardent supporters of the new programme. He co-authored of a number of the proposals to establish the department and was a vocal

[6] "Satisficing is an alternative to optimization for cases where there are multiple and competitive objectives in which one gives up the idea of obtaining a 'best' solution. In this approach one sets lower bounds for the various objectives that, if attained, will be 'good enough' and then seeks a solution that will exceed these bounds. The satisficer's philosophy is that in real-world problems there are too many uncertainties and conflicts in values for there to be any hope of obtaining a true optimization and that it is far more sensible to set out to do 'well enough' (but better than has been done previously)." – International Institute for Applied Systems Analysis (IIASA)

supporter of the programme to the administration. The Dean's openness in many ways prevented the Faculty Council from stopping the creation of the new programme. A key aspect of the Dean's strategy was presenting Systems Design as a test bed for new approaches to engineering education. This would allow the department to innovate while protecting it from the other departments, and vice versa.

The issue of CEAB accreditation was one that sparked significant debate among the founding members. The members agreed that professional standing was required for continued success. Such standing ensured a level of provincial funding equal to that of the other engineering programmes. Where the members differed was in how to obtain professional standing. One group felt that meeting the criteria of the nascent CEAB was the best route. Their belief was that CEAB accreditation was to become the singular factor that differentiated between professional and non-professional programmes. The other group felt that the programme should pursue its own vision without reference to the CEAB criteria. In the end the programme was developed without direct reference to the CEAB criteria. Having been developed, the program was found to meet the criteria without the need for further changes.

The President of UW exerted significant influence on the design of the Department. The Department of Design originally planned to develop a department of Environmental Studies-Architecture. This department would be part of the Faculty of Engineering and would maintain the focus on Environmental Systems Design developed as a part of the Expo '67 preparations The 1968-69 calendar makes reference to this new group as joined with the Department of Design. [250] Between the publishing of the calendar and the beginning of the academic year the President chose to cleave the departments into separate faculties.

The design of the department was strongly influenced by two factors. The first factor was the compatibility contraint between the department and the rest of the engineering faculty. Whether the Faculty Council was responsible for introducing the compatibility constraint, or whether the founders desired compatibility is not known. What is known is that the original design document identified compatibility as a key goal. [159] The most obvious manifestation of the compatibility constraint was the need for students to be able to easily transfer between Systems Design Engineering and the other engineering departments. This constraint had three consequences. First, the department was forced to have separate courses for different topic areas. These courses had to adopt the traditional mechanisms of lectures, tutorials, and laboratories. Second, the core programme had to include much of the same material as the traditional engineering programmes. Third, any courses that covered material similar in character to that covered in courses in the other departments had to be of similar orientation. For example Systems Design could not introduce a systems approach or applications of complexity theory into a course that covered the Mechanics of Deformable Solids given that Civil Engineering offered a similar course using more traditional methods. The concern was that in advanced courses any differences in underlying techniques or understanding would overly complicate the teaching and learning of the new material. Taken to an extreme, if Systems Design Engineering were to reinvent the teaching of engineering then it could not be part of the faculty. These three restrictions had a significant impact on the nature of the programme and the number and types of innovations that could be implemented. The Faculty Council is composed of representatives from each department. Accordingly, it is difficult for a single department to effect radical change[7]. The second, and equally strong influence on the design of the department was the lack of resources. The founders had some funds available to them as a result of the Expo '67 contract. If the proposed design for the department was too radically different, the department would need to purchase and maintain its own infrastructure. The Export '67 funds, while sufficient to start a new programme, would not be sufficient to support such a radiacal restructuring of engineering education.

5.1.8 Design solution

This section discusses the early design of the Department. The discussion is complicated by the fact that while the first students were admitted in 1969-70 the structure of the department and its curriculum did not reach a steady state until 1972-73. The transient changes are the most interesting as they demonstrate the radical nature of the original design of the department. Even with the support of the Dean of Engineering, a sizeable amount of funding, and a university willing to support innovation, the original vision of the founders settled into a more conventional form. Unfortunately, while documentation

[7]However given the size of the council, in general three departments working in concert can effect arbitrary changes.

on the steady state form of the department is rare, documentation on the transient aspects of the department is even harder to obtain.

The initial design of the programme is documented by Kesavan et al. [159] This document succinctly describes the original plan for the programme.

> "The programme consists of a three year core of studies involving three major topics, namely: Physical System Theory, Human Systems Engineering, and Socio-economic Systems. This core in turn leads into a fourth year in which the student can elect to study particular kinds of systems in detail, either directly for eventual work in industry, or in preparation for one more year of study toward a Master's degree."

5.1.8.1 Inputs

Faculty

Where possible and financially feasible faculty members from other departments and faculties were hired to teach discipline specific material outside of the expertise of the Systems Design faculty members. Content unique to the department, for example socio-economic systems modelling, was to be taught using traditional methods by faculty from within the department.

Emerging adults

To attract its first students the department undertook two activities. The first was the development of a relatively traditional recruitment pamphlet that was distributed to prospective UW engineering students.

> "There's a new and unique undergraduate programme now being offered by the University of Waterloo. It's called Systems Design; it's an honours programme leading to a Bachelor's of Applied Science (B.A.Sc.); it has been specifically created for people who want to be aware of and able to solve problems lying at the interface of technology and the human environment. If you are technically oriented and also have a strong parallel interest in social and human problems, you should be looking into Systems Design. "[237]

The second recruitment technique was to contact prospective engineering students who had applied to other programmes. The officers of the department obtained the list of applicants to Waterloo Engineering for the 1969-70 academic year. From this list they selected those who appeared compatible with the department and called them personally. The other engineering departments adopted this practice in the subsequent year.

5.1.8.2 Parameters

Infrastructure

Within the constraints of UW the department chose to trade space for research laboratories for a group of dedicated classrooms. These rooms were adjacent to each other and to the offices of many of the department's teaching assistants.

Goals

> "The undergraduate course in Systems Design Engineering at Waterloo has been created to provide the student with a broad background and capability in:
>
> - Systems Analysis, Simulation, Optimization and Design.
> - Human and Environmental Systems Engineering
> - Social and Economic Systems.
>
> This programme is specifically oriented towards developing graduates who can solve problems lying at the interface of technology and the human environment." [233]

Processes

The constraints and criteria related to processes were implemented as structures. Again, there is no documentation, save the original proposal, in which this information is recorded.

Content

The department recognized early on the difficulty in providing a limited amount of information on a wide variety of interdisciplinary topics. The philosophical position of the founders was that a basic understanding of a field would be sufficient, so long as the student could communicate with experts in that field. As professionals the students would be aware of their limitations and would not undertake activities alone that were better left to these experts.

> "It is the intention, however, within interdisciplinary frames of reference, to provide the student with perspective knowledge in [physiology, psychology, sociology] that he can utilize to serve his purposes in Systems Design in the same way that he uses knowledge of physics, graphics, and electronics, without being a physicist, artist, or electrical engineer." [159]

The founders also adopted a number of the central tenets of the scientific approach to engineering education. Accordingly a series of detailed courses in mathematics preceded the majority of the field-specific survey courses.

In terms of specific courses and course areas the department incorporated:

- Physical systems (electrical, civil, mechanical)
- Graph theoretic modelling (General systems theory)
- Human factors
- Human environmental physiology
- Human psychology
- Systems behaviour
- Design
- Computer simulation of systems

The department also chose to work closely with the newly affordable minicomputers available at UW.

> "The student's preparation in computers is exploited to lay adequate emphasis on simulation models both for the formulation and the solution of problems

> which provide a most effective link to studies directed towards computer-aided design."

Instruction in the use of computers was originally incorporated into the study of physical systems through a course in system simulation. As computers became less expensive, and by extension more accessible, their study and use became a separate topic within the department[8].

Structures

The structures that defined the department and its curriculum received the most attention in the original design. These structures were intended to ensure that the original process goals would be maintained. The majority of the structure related to curriculum.

The original vision for the curriculum consisted of eight courses corresponding to the eight terms spent on campus by the students. The courses were in effect a bureaucratic fiction that would allow the professors in the Department to offer courses that were as adaptive and innovative as possible. The eight-course vision was quickly modified. The number of courses was doubled to 16. Each term now consisted of one course in theory and one comprehensive laboratory course. This laboratory course was a major curricular innovation.

A traditional course might have a lecture section and a laboratory section. The laboratory would exercise the theory learned in the lectures. In a given term a student might take multiple labs each focusing on a different topic. The comprehensive laboratories were intended to link together all of the theory learned during that term. When there was a single theory course, to have a single laboratory course was not a novel concept. The novelty came as the theory courses were repeatedly split into smaller, single-topic courses, while the laboratory course remained intact. The intent was for the laboratory course to merge together the different theories in tangible ways.

The most innovative aspect of the Systems Design Engineering curriculum was the manner in which design and systems concepts were incorporated. The original vision was

[8]Ideally, the use of computers in engineering would have been an option offered by the department from its inception. However when the department was designed the resources required were not available.

to integrate design activities and systems approaches throughout the curriculum. In effect these topics would be merged into the overall fabric of the department and would not exist as distinct courses. This option could not be pursued because of the need for compatibility and lack of resources discussed earlier. The solution was to develop a new type of course. The original vision of one course in theory and one laboratory course was augmented with one workshop course. Again as the theory course was split, the workshop, like the laboratory, remained unified.

> "The purpose of the workshop is two-fold. First, it provides an opportunity for the student to integrate the material derived from his academic lectures and to apply the knowledge so obtained to solution of a progressively more complex series of real-life problems; secondly, it makes room for lectures and seminars on various design theories and allied topics which are essential to the understanding of the process of design.
>
> As mentioned earlier, the Systems Design Workshop, in fact, will be a focus of endeavour in each semester in which the transdisciplinary nature of the programme is emphasized, and in which the student has the opportunity to develop and practice his acquired skills and knowledge in a systems approach to synthesis, design, and the solution of relevant problems."

As the number of courses multiplied the department grouped them by topic area. Each course was assigned a three-digit number. The digit in the 10's place referred to the topic area covered by the course. This structure not only simplified administration for the students but also simplified curriculum planning. The different topic areas and the number of course courses in each once steady state had been reached is described in table 5.3.

From the beginning Systems Design Engineering has offered more options than any other engineering department at UW. Although students have received formal recognition only for options offered by the Faculty, by defining the options the department has committed to its students that the courses would be scheduled without conflicts.

As with the other departments with the Faculty, Systems Design Engineering developed a number of areas of specialization. The original areas of specialization were:

Digit	Topic Area	Core
1	topics in mathematics	10
2	computer systems	5
3	socio-economic systems	4
4	human systems	2
5	physical systems	4
6	the design of engineering systems	7
7	human communication systems	0
8	engineering sciences	6
9	laboratories	4

Table 5.3: Systems Design Engineering curriculum categories and core counts

- Communications
- Human Systems Engineering
- Computer-Aided Design
- General Systems Design
- Industrial Product Design
- Socio-Economic Systems

The Systems Design Engineering curriculum included more electives, allowed students to take electives earlier in the programme and allowed students to select from a larger set of electives courses than that of the other engineering departments. The elective offerings forced the students to take responsibility for their education but allowed them the flexibility to create individualized curricula. As a relatively small department Systems Design Engineering could not offer a complete spectrum of elective courses covering all aspects of physical, socio-economic, and human systems. To address this issue students in SYDE could take, in principle and subject to the approval of the Associate Chair for Undergraduate Studies, technical elective courses from any source on campus.

Students in Systems Design Engineering did not participate in the common first year engineering curriculum. While the material covered in the SYDE equivalents was similar, faculty in the department were given the opportunity to develop alternative teaching approaches.

Two other structural innovations deserve note. The first was the creation of the position of Class Professor and the Class Professor Hour course. One Class Professor was assigned to each on-campus class. This Professor was a liaison between the class, their professors and lecturers, and the Department. The Class Professor could use their course for whatever ends they saw fit. The most common use of the Class Professor Hour has been to present guest lecturers on topics of interest to the classes.

The other structural innovation of note was the development in the 1990s of the Student Advisory Group on Education (SAGE). The SAGE membership consisted of representatives of the classes, the Associate Chair for Undergraduates, and the Class Professors. Through SAGE students and faculty members could inform each other of the state of the undergraduate engineering programme.

5.1.8.3 Transformation

There are no records of design decisions related directly to this component.

5.1.8.4 Outputs

There are no records of design decisions related directly to this component.

5.1.9 Design evolution

This section discusses the evolution of the System Design Engineering design after it achieved a steady state in 1972-73. Many of the transient changes to the Department discussed in section 5.1.8 related to how well Systems Design Engineering aligned with the traditions and assumptions of the other departments within the Faculty. A key question is how well Systems Design Engineering has been able to maintain an independent focus and identity during the more steady state portions of its evolution.

With respect to the human dimension the department started with a faculty complement of 16 and an initial class size of 61. The graduating class sizes have grown steadily and have reached a stable level of approximately 90 students graduating per year[9]. The number of active professors has remained relatively constant, peaking at 18, and has since returned to its original level of 16. While it has never comprised more than 18 individuals

[9] In contrast the entering class sizes exceeded 90 shortly after the department was formed.

over the last 30 years the Department has employed approximately 60 professors. Given this high rate of employee turnover the department has accumulated numerous professors emeriti. Compared to the other Engineering departments at Waterloo, Systems Design Engineering has always had a relatively small student and faculty complement.

The Systems Design Engineering curriculum has experienced what palaeontologists would term punctuated equilibrium. Since achieving steady state the curriculum has undergone radical change twice. Accordingly discussions of the evolutions of the curriculum make reference to four points in time. The curriculum of 1972-73, the beginning of the steady-state, are considered most representative of the visions of founders and represent baseline measurements. The 1981-82 academic year brought with it a drop in the number of courses per term from seven to six. This reduced the number of undergraduate technical slots from 52 to 44 and required major changes to the curriculum. Similarly, the 1990-91 academic year further reduced the number of technical slots to 34, necessitating another round of curricular change. As these two years represented significant changes to the curriculum they are included in the investigation. For the purposes of comparison the curriculum for a recent academic year, 1999-2000, are also included.

The reduction in the number of courses was to be compensated for by increasing the amount of material in each course. The reality, as measured by the course descriptions, was that in many cases the amount of material did not increase sufficiently to make up for the reduced number of classes. The number of distinct topics covered by the students has, in general, been dropping steadily since the Faculty was founded.

With respect to curriculum the course categorizations presented in table 5.3 provide a framework for discussion. The list of topics has changed once. In the 1978-79 academic year the "topics in mathematics" field was changed to "topics in applied mathematics" and the "human communication systems" field was changed to "communication and information systems". This second change was important as it represents a significant shift in the orientation of the department. "Human communication systems" focused on different approaches to enabling and enhancing communication between humans. This focus was in keeping with the department's goal of merging the study of human, socio-economic, and physical systems. In contrast "communication and information systems" emphasizes the technologies of communication and computing. This topic is similar to those covered in electrical and computer engineering or computer science. The merging of concerns essential to the vision of Systems Design Engineering is absent from this new topic area.

All courses offered by the department since 1972 have followed this numbering scheme. The basic category information can be augmented in a number of ways. The first measure examines only core courses. These courses define the material that the Department recognizes as being essential for all Systems Design engineers. Figure 5.3 depicts the evolution of the percentage of core courses in each category. Notable trends in this measurement

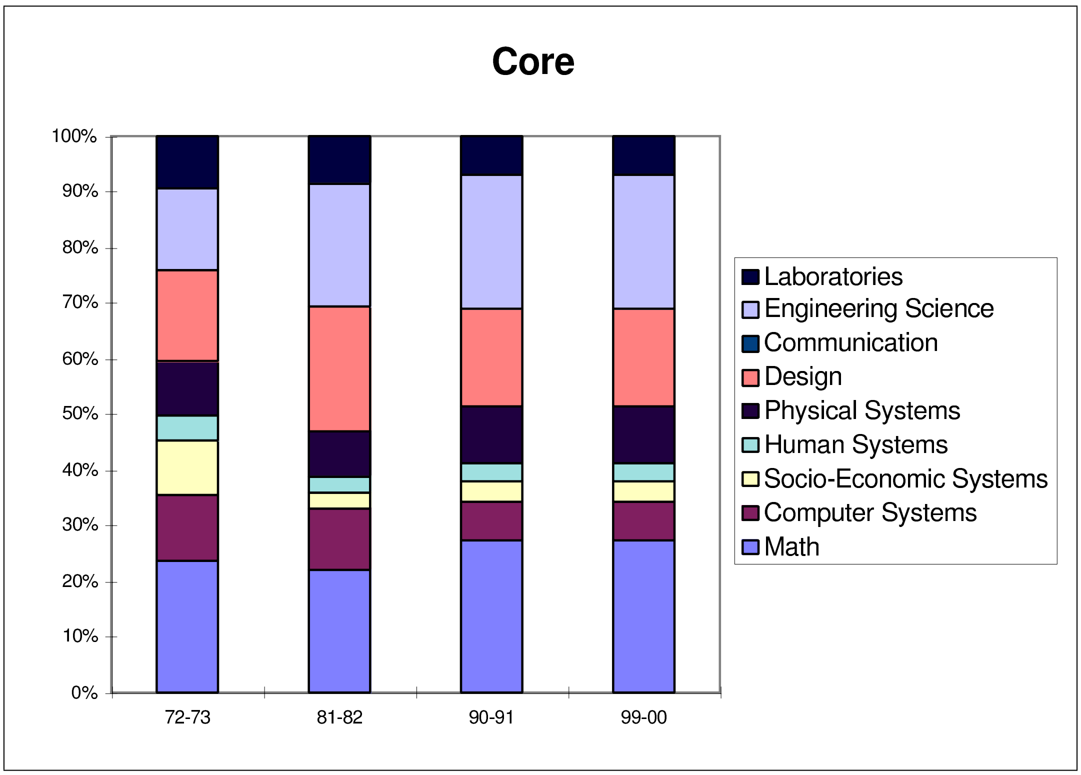

Figure 5.3: Evolution of the Systems Design Engineering core curriculum

include a complete lack of Communication courses, increases in Engineering Science and Mathematics, and reductions in both Socio-Economic and Computer Systems.

The second measure measures the distribution of all of the courses offered by the department to undergraduate students. This measurement includes electives and transition courses that can be taken by both graduate and undergraduate students. Graduate courses are believed to align more closely with faculty interests than undergraduate courses. Accordingly this measurement represents the impact on the undergraduate curriculum of changing faculty interests. Figure 5.4 depicts the evolution of the percentage of core courses in each category. The undergraduate curriculum has experienced an evolution similar to

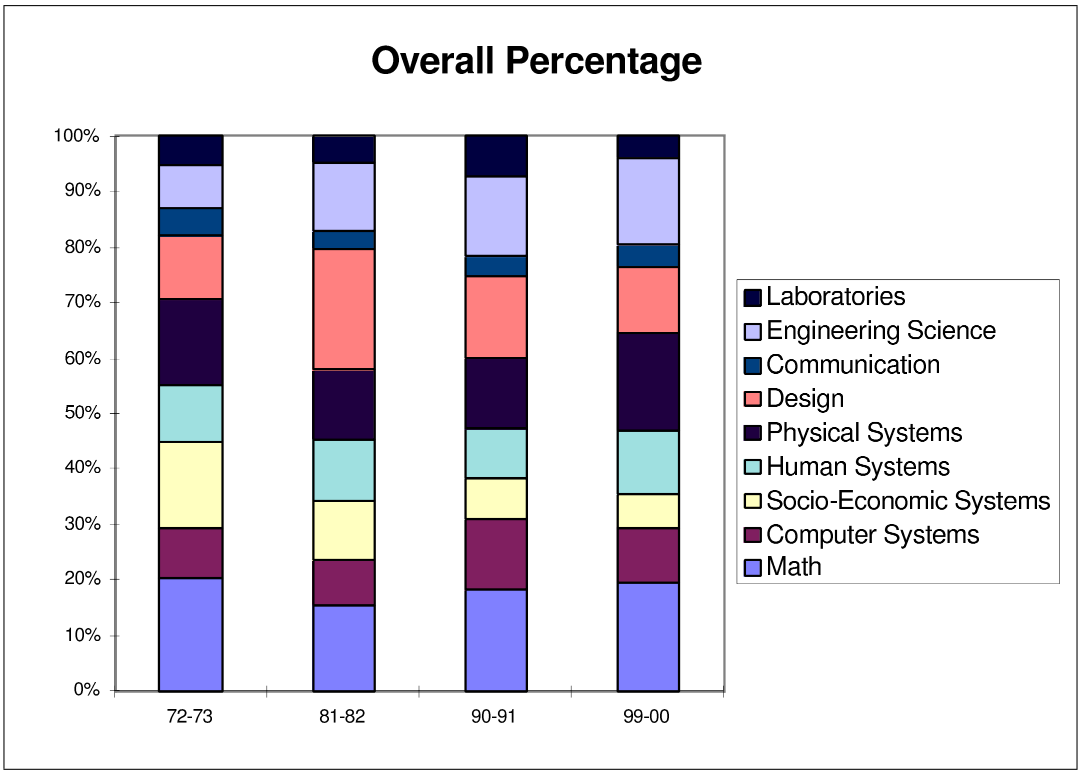

Figure 5.4: Evolution of the Systems Design Engineering undergraduate and transition curriculum

that of the core. Engineering Science and Mathematics have been strictly rising while Socio-Economic systems has been strictly falling. The addition of the electives and reveals some additional insights. Communications courses exist only in the electives and have maintained a relatively steady presence. As described earlier this steady presence must not be confused with an unchanging emphasis. What appeared to be a drop in Computer Systems was in fact a shift of material from the core to the electives and transition courses.

This shift may be explained by the gradual integration of computers throughout the curriculum, resulting in less need for dedicated courses. The final additional insight is that the percentage of Physical Systems courses, which appeared to have remained constant in the core, has in fact been growing at the expense of the Design courses.

It is interesting to examine the nature of the transition courses in Communication and Physical Systems. They include *SD575 Pattern Recognition*, *SD553 Neural Networks and Fuzzy Computing*, and *SD573 Pattern Recognition*. These courses do not align well with the categories established when the Department was designed. Instead they are indicative of the shift in emphasis that took place in this topic area.

The next measure examines the percentage of faculty research devoted to the different categories. With the assistance of published information on faculty research interests, all professors, associate professors, and assistant professors active during the sample periods were placed in one or more categories. Given that individual professors could research multiple areas or a single area, the weightings described in table 5.4 were assigned. For

Categorization	**Weight**
Only Area	3
Primary Area	2
Secondary Area	1

Table 5.4: Faculty research weightings

example, a professor who researches in cognitive ergonomics would add 3 units to Human Systems, whereas a professor researching the application of graph theoretic modelling to physical systems would add 2 units to Physical Systems and 1 unit to Mathematics. The percentage allocated to each category was calculated based on the total number of professorial units in a given year. Figure 5.5 depicts the evolution of the faculty percentages in each category. This measurement reveals how the curriculum offerings have been insulated from changes to the faculty complement. The large rise in the number of Physical and Computer Systems faculty and the drop in the number of Design faculty have not affected the course offerings in these areas to the degree that one might expect. This conclusion is confounded by a number of factors. First, many courses in the early Systems Design

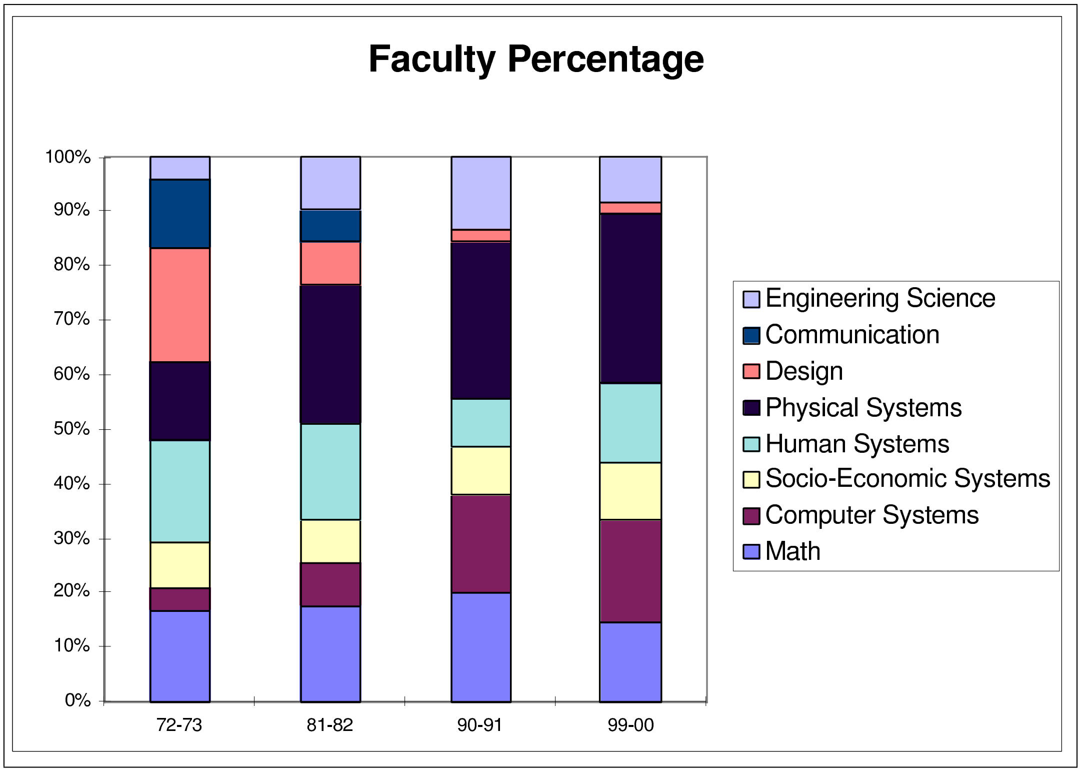

Figure 5.5: Evolution of the Systems Design Engineering faculty research interests

Engineering core are taught by members of other departments and faculties. There are no publicly available historical records of these external teaching assignments. Second, a professor researching one area may be assigned to teach a course in a different area. Again there are no publicly available historical records of these internal teaching assignments. Finally, the categories assigned to faculty members research interests are not always the same as that assigned to the courses they are known to teach. For example the professor who in 2000-01 taught *SD553 Neural Networks and Fuzzy Computing*, which is categorized as a Physical Systems course, has been categorized as researching Mathematics and Computer Systems.

The final measurement relates to the design and workshop courses. These courses are linked together for two reasons. First, because the workshop courses, as described in section 5.1.8.2, were intended to provide students in Systems Design Engineering with design experience. Second, because the workshops were considered courses and were categorized as The Design of Engineering Systems. Table 5.5 summarizes the number of workshops and the course offerings in design during the periods of study. Overall Systems Design Engineering has been able to maintain, within the core of its curriculum, a relatively steady percentage of design and workshop courses. It is interesting to note that during the first major change to the curriculum the Department was able to maintain its workshop offerings as well as increase the number of design courses. During the subsequent revisions the curriculum reverted to its original proportions. Also interesting is that the number of non-core design courses has been dropping steadily over the last 20 years. It should be noted that workshop-style courses, using the rubric of "capstone design experiences" are now the norm in engineering departments across North America.

		Design			**Workshop**	
Year	**Core**	**Courses**	**Core**	$\%_{core}$	**Core**	$\%_{core}$
1972-73	42	7	7	18	6	14
1981-82	36	12	8	22	6	17
1991-92	29	8	5	17	3	10
1999-2000	29	6	5	17	3	10

Table 5.5: Evolution of the Systems Design Engineering design and workshop courses

The Department has also been unable to maintain some of the structural aspects of its curriculum. By the beginning of the steady state phase, the goal of a single theory course had been dropped. Shortly thereafter the comprehensive laboratories were also split into distinct courses. There is no documented rationale for splitting the laboratory courses. Anecdotally the primary reason was that the courses were too difficult to design and teach. This explanation is somewhat bolstered by the nature of the curriculum support materials available to engineering professors. The vast majority of textbooks and course packages assume that any laboratory work will involve only the material they cover. In a given term the comprehensive laboratories could, for example, attempt to merge the study of magnetism, fluid mechanics, and materials science. Not only is it difficult to design laboratory exercises that integrate all of the content, but it is also extremely difficult to find faculty and teaching assistants who are skilled in all of the areas separately, let alone in combination. Over time the comprehensive laboratories reverted to the same format and content as traditional engineering laboratories.

Other evolutionary changes worthy of note include:

- The department has developed and maintained a completely separate admissions process.
- The number of research groups has increased to seven[10] and are distinct from the curriculum offerings.
- The department introduced the idea of a retreat in the late 1980s. The retreat was intended to bring the faculty members together to discuss the present and future of the department. Records exist for the retreats held in 1993 and 1994. The last such meeting was in 1996.

5.1.10 Results and discussion

5.1.10.1 Faculty of Engineering

> "Feeling cocky about our interdisciplinary engineering program - the only one of its kind in Canada - we soon realized we were regarded as the black sheep - the 'artsy engineers'." [239]

Beyond enforcing course reductions, the Faculty of Engineering has generally allowed Systems Design to evolve as its members desired. Recently the Faculty removed from the department one of its key strengths. To simplify the accreditation process all of the departments within the faculty now share a common list of technical electives. The Undergraduate Chair in Systems Design has historically allowed significant leeway to students pursuing areas outside of traditional engineering. This flexibility, one of Systems Design's hallmarks, is no longer possible.

[10] Ergonomics, Human Factors and Biomedical Engineering; Modelling and Simulation; Pattern Analysis, Machine Intelligence and Robotics; Signal and Image Processing; Societal and Environmental Systems Engineering; Software Engineering and Optimization Software; Systems Theory

As an incubator for new ideas in engineering education the Department has met with modest success. In particular many of the Faculty Options were developed in the Department. The Faculty has also adopted the combined bachelor's-master's programme pioneered by the department.

5.1.10.2 University of Waterloo

Aside from an anecdotal reference by a past president that likened the department to the University's "crown jewel" [9] there is little evidence of any significant direct interactions between the department and the university administration. However, the department has been home to a number of august persons who have figured prominently in administrative roles at the University. Such figures include a past president, multiple senators, and numerous associate deans.

In terms of measurements the early days of the department were turbulent. Of the 61 students who started the programme in 1969, 36 finished. Neither their cooperative placement rate nor their entrance averages are known. As the programme has matured the failure rate has dropped steadily while the placement rate and entrance average have risen. The University does not release detailed statistics on failure rates and does not record over the long term cooperative placement rates. For the Systems Design class of 2003 the entrance average was in the neighbourhood of 95% and the placement rate was also in the high 90s[11]. Systems Design is now habitually among the most challenging engineering programmes in terms of gaining admission.

5.1.10.3 Engineering Profession

Systems Design has interacted with the profession through accreditation and competition. The department received CEAB accreditation on its first attempt. Given the rapid pace of change in the early years and the significantly different approach to engineering education, obtaining accreditation implies that the profession saw, and continues to see, value in the department.

The profession, through the provincial licensing bodies and the CCPE, hosts a number

[11] According to a past departmental officer the failure rate was between one and two percent.

of engineering competitions across Canada. Students in Systems Design can compete in the Ontario Engineering Competition (OEC) and contingent upon their performance can continue to compete at the Canadian Engineering Competition (CEC). In recent years the department has excelled at both competitions. In 1998, which is arguably the high water mark, the department won eight of twenty-one possible awards at the OEC, the majority of the awards being for first place. That same year the department won more awards at the CEC than any other engineering faculty.

5.1.10.4 Funding Bodies

The relationship between the department and the various funding bodies has not been as convivial as might have been hoped. There remain no dedicated mechanisms for faculty members to receive funding to research systems theory, design, engineering education, or transdisciplinary approaches. To the department's credit this lack of dedicated mechanisms has not translated into a lack of research funding. Although exact numbers are not available, the faculty members and graduate students within Systems Design Engineering appear to have enjoyed some success in obtaining research funds. With respect to NSERC, the department has received funding from a number of the engineering GSCs[12]. The breadth of activities within Systems Design Engineering is partially evidenced by the fact that one of its graduate students is being funded by the SSHRC.

NSERC has recently created a number of Chairs in Design. At first glance this would seem to be an acknowledgement of the importance of design and a commitment to design as a topic of study. Such a commitment would likely benefit Systems Design Engineering. A closer examination of the duties and orientation of the Chairs reveals that this is not the case. [189] The NSERC Chairs in Design focus on environmental or process issues, generally oriented towards Mechanical Engineering, not on design as a broad topic of study and research.

[12] This research was funded in part by an NSERS PGS-A from the Industrial Engineering group.

5.1.10.5 Real life

Students in Systems Design tend to be involved in entrepreneurial ventures. A one-time survey undertaken by the department found that 22% of the graduating class of 1984 owned their own companies. Unfortunately similar statistics for other programmes are unavailable. Anecdotal evidence suggests that Systems Design students are perceived as being more innovative and entrepreneurial in their careers.

In the wider context Systems Design Engineering is best summed up by the question asked most often of its students and graduates. “What is Systems Design Engineering” is a question that was first asked in 1969 and continues to be asked to this day.

5.1.10.6 Internal

There is little record of the opinions of Systems Design Engineering’s members as to the effectiveness of the its approach to engineering and engineering education. The faculty members have produced a small number of academic papers describing various aspects of the department. [160, 208, 211] There have been no such papers produced since the early 1980s. In their early yearbooks the department’s students discussed at length their opinions of the department, its curriculum, and its faculty members. [237, 239, 240] Unfortunately the yearbooks produced after the early 1980s no longer contain such discussions. [271] Perhaps the best sources that describe the internal view of the department are the published and unpublished documents written by, and distributed among the faculty and students. Such documents include workshop symposia [224, 225, 209, 175, 212, 45], positions on expansion [134, 10, 6], promotional materials [127, 73, 68, 74], and research reports [77, 70].

Terminology

All of the discussions of the Department of Systems Design Engineering listed above use one or more of the terms ‘interdisciplinary’, ‘transdisciplinary’, and ‘systems approach’. Two interesting questions are whether the department members have tried to develop personal definitions for these terms and whether these terms are generally given the same, or similar, definitions by the various members of the department.

As described in table 5.1, the terms ‘interdisciplinary’ and ‘transdisciplinary’ were explicitly defined in the original proposal that described the department. [159] The term 'transdisciplinary' has since ceased to be used in departmental communications. [6, 74, for example] This change in terminology is indicative of the difficulties encountered by the Department in maintaining this aspect of its character. The term 'interdisciplinary' is now used most commonly to describe the department. [74]

The definition of 'interdisciplinary' presented in [159] is not limited to engineering. It refers to "various academic disciplines", not to "various engineering disciplines". It is difficult to determine whether the department has been able to maintain this open definition. Systems Design Engineering does not permit its students any more latitude in course selection than do the other engineering programmes[13]. It does however provide more opportunities for its students to take courses from other programmes. [255] From this perspective Systems Design Engineering has restricted the definition of 'interdisciplinary' to be primarily within engineering. None of the remaining documents that use the term 'interdisciplinary' provide a definition.

> "By systems we mean a philosophy of how we see the world, its problems, and our efforts to address them. Our scope is not limited to technology; we are also concerned about the human, social, environmental and economic factors involved in a problem." [68]

The term 'systems approach' appears throughout the Systems Design Engineering literature. Unlike 'transdisciplinary', but as with 'interdisciplinary', there are no explicit definitions for this term. There are a number of fragmentary definitions, such as the one given above, but there are no documented attempts to define the term in a comprehensive manner. Given that this term is so pervasive, the lack of such activities is cause for concern.

Self image

> "So, Systems Design is really just Engineering in General? Superficially, yes. The distinction is our explicit attention to two things: Design and Systems." [68]

[13]This has been assured by the harmonization of the elective policies across all engineering programmes.

The question "What is Systems Design?" has been posed since the first days of the department. [237] Unlike the definitions of 'interdisciplinary' and 'systems approach', there has been much written on this topic. The documents that discuss expanding the department provide a glimpse of the essential aspects of the department from the perspective of the faculty.

> "...we are interdisciplinary, we take a systems world view, we adopt an explicit engineering design framework...Our common ground, and our sense of mission, should be a reaffirmation of the systems philosophy and the importance of design in an engineering context...I believe a common commitment to the systems modelling, analysis and design approach to engineering problem solving, with evolving emphasis in particular disciplines allowing us to respond to changing societal needs as well as our personal enthusiasms, is what Systems Design Engineering is all about." [152]
>
> "Our department will expand only if such expansion allows it to further its mission and preserve its essential character..." [26]
>
> "...our design philosophy..." [26]
>
> "Systems Design maintains a long and well-established sense of community."[27]
>
> "The Systems Design Engineering program is currently recognized for its students who are flexible with all-round skills and who adapt easily to meet changing needs and demands." [10]
>
> "The program educates young people to become engineers who design systems. Within this very general objective, the concentration, as Engineers, is on those systems that can be described quantitatively, using Science and Mathematics." [74]

While these documents all speak to the existence of some core elements that define the department, they all fall short of providing workable definitions. Neither the "design philosophy", nor the "essential character", nor the "sense of community" are described in any further detail. Again, the fuzzy nature of the terms is both a strength and a weakness. The strength is that the ability to be flexible and adaptable is enhanced. The weakness is that cohesion, and the sense of purpose that accompanies it, is lacking.

Workshops and design courses

> "One of the foundations of the Systems Design Engineering program is the study of the Engineering Design Methodology. This is accomplished through a series of five interdisciplinary project-oriented courses, together known as the 'Systems Design Workshop'." [74]

> "A set of special interdisciplinary *Systems Design Workshop* courses, stressing design methodology, also forms an essential part of the program." [73]

The Systems Design Workshops are seen as an essential aspect of the programme. Unlike definitions or self-image, the workshops have a tangible form that is experienced by all Systems Design students and most faculty members. For the purposes of this discussion the workshop courses are considered along with the introductory courses in design and systems with which they share a topic designation.

Figure 5.6 and table 5.6 present the results of an assessment of the evolution of the workshops since 1984. [224, 225, 209, 175, 212, 45] Unfortunately there are no records available for previous years. All of the measurements in the figure are percentages of the total number of workshops in that year. The assessment consists of three components.

Year	1984	1986	1987	1995	1999	2000
Avg. References	3.5	3.8	3.7	4.4	2.8	2.3
Stdev. References	3.1	2.9	3.9	2.5	2.0	1.5

Table 5.6: Workshop references

The first was an assessment of the percentage of workshop supervisors who were faculty members within Systems Design Engineering. The second was an average and standard deviation of the number of references provided in each workshop summary. The third

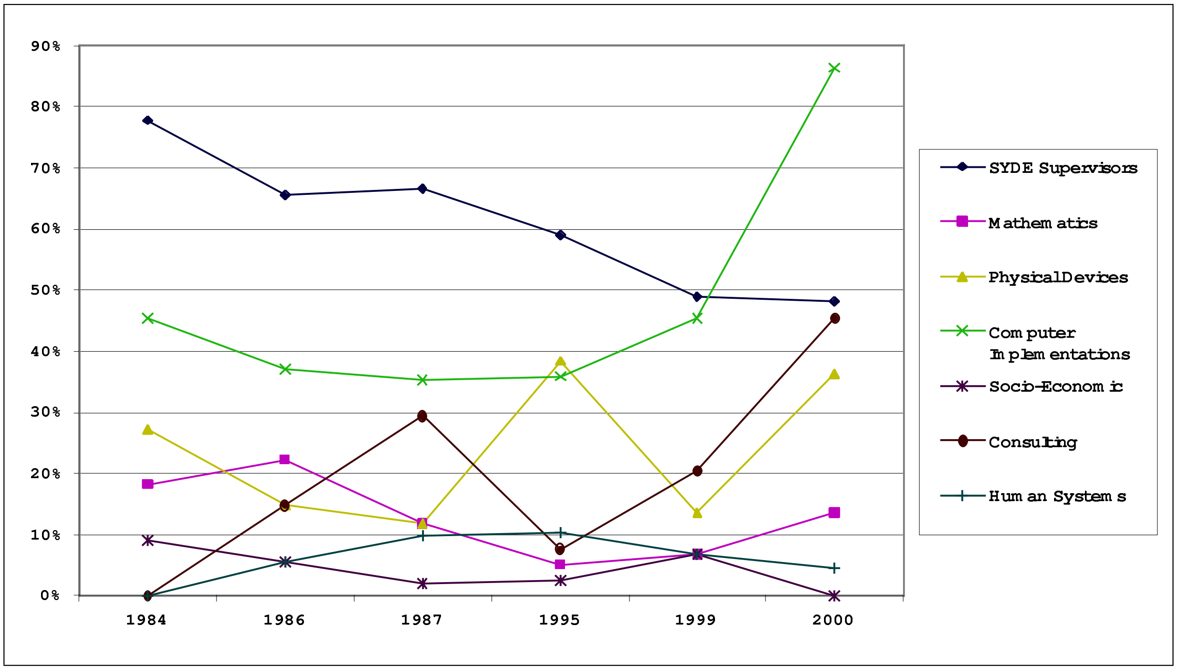

Figure 5.6: Evolution of the Systems Design Engineering workshop topics and supervision

component was a subjective assessment of the primary focus of the workshop. The possible assessments and their meanings are as follows:

Mathematics workshops focused on deriving or applying mathematical approaches to an engineering problem

Physical devices workshops focused on producing a working prototype of a physical device

Computer implementation workshops focused on implementing an existing algorithm or process, or on integrating existing computer software

Socio-economic workshops focused on modelling socio-economic issues and on decision making

Consulting workshops gathered and presented information on a topic

Human systems workshops focused on measuring or enhancing human performance

As depicted in figure 5.6 the percentage of supervisors from within the Department of Systems Design Engineering has been steadily decreasing. Generally speaking the number of references has also been decreasing. Of the workshop topics the percentages of both *computer implementations* and *consulting* have been steadily rising. There are no significant trends with respect to the other topics.

The nature of the sources and the assessment technique makes drawing substantive conclusions from figure 5.6 and table 5.6 problematic. The assignment of topics to the workshops was subjective and as such subject to both bias and inconsistency. As different professors coordinated the workshops in different years, the reference counts may be more indicative of their preferences than of declining rigour on the part of the students. What cannot be argued is that fewer systems design engineering professors are supervising workshops. Unfortunately the available sources do not provide sufficient information to explain this trend. One hypothesis is that students in Systems Design Engineering are exploiting the interdisciplinary nature of the program.

The student perspective on the design and workshop courses is best summarized by the students themselves.

> "In 2A we were the first to witness and experience the large scale introduction of what was heralded to be a most important learning experience – the Workshop. In theory it was to be 'a problem and project oriented course wherein emphasis is placed on designing and presenting creative solutions to real-life problems'. Students were divided into groups of 5 or 6 to research, discuss, formulate and present solutions to designated problems. Following, of course, a disciplined design approach. In reality five people would sit around and have heated arguments over what to do." [237]

> "In as far back as its earliest stages, in the 1B synthesis course, the workshop philosophy stuck out like a sore thumb. The idea is to teach you to work together, in harmony, as a design team; to tackle a design problem and to come up with a solution, in the form of the best alternative. . . at the time of this article, I suspect there will be some rather mad rushes in about 2 months time to finish what should have been done 5 months earlier." [237]

> "The Workshop concept, in spite of operational problems, did help me to solidify some of my own explanations of Systems Design. Since that time most

of us have defined it to suit our needs, whether they are job needs or academic security needs. Those who didn't, number in casualties of our course." [237]

The students also provided a perspective on the individual courses. A selection of their comments include:

F75 SD161 Systems Behaviour (M.L. Constant) Systems, sub-systems, and sub-sub-systems. Inputs and outputs. Components and the Environment. Plus, the great container port simulation. [239]

F76 SD161 Systems Behaviour (M.L. Constant) Introduction to bookstore operations; purposive, purposeful, and porpoiselike communication; manual stimulation and sleep deprivation; ritual chanting of the word 'systems'. Be prepared to supply histograms when not asked for. [240]

S76 SD162 Systems Design Methodology (P.H. O'N. Roe) As discovered very soon, this course could more appropriately be called 'Systems Design Mythology.' [239]

S77 SD162 Systems Design Methodology (Mythology) (P.H. O'N. Roe) How to be a systems design engineer in 11 easy steps. Design as an iterative process: keep trying until you get it right. [239]

W77 SD261 Workshop I (K. Hahn) Who other than Kish would be more appropriate in handling one of our first large scale, real-world projects and emphasizing 'teamwork and the systems approach?. *Permafrost: Planning, technology and design for a new Arctic city* [239]

F77 SD262 Workshop II (P.L. Seeley) Who else would demand that problem statements be in on time and then discuss them with the group two weeks before presentations? Who else would sometimes read newspapers during presentations? [239]

W80 SD362 Systems Design Workshop 4 (Prof. Wills) Cross referenced with SD302 and SD322. Introductory billboard engineering. Don't sell your Letraset stock yet! [240]

F80 SD461 Systems Design Workshop 5 (Prof. Rabideau) Introduction to mark deflation. Deadlines will be enforced. Seriously. [240]

S81 SD462 Systems Design Workshop 6 (Prof. Rabideau) Remember this? You were supposed to have started it four months ago. At least you can tell your boss you had something published. [240]

While these comments are clearly intended to be humorous, they do provide a flavour of the student perspective on the workshop and design courses.

There is little direct evidence describing the opinions of the Systems Design Engineering faculty towards the workshops. Indirectly it it possible to conclude that the faculty do not share a common vision of the workshop objectives, deliverables, and evaluation techniques. The evidence to support this conclusion comes from an internal document that was prepared, presumably by faculty members within the department, to describe the workshop sequence. [8] The document was divided into the following sections:

- The workshop sequence
- Systems Design workshop objectives and evaluation
- Evaluation guidelines
- Project deliverables
- Problem definition
- Log books
- Progress reports
- Final report
- Supervisory guidelines

One can assume that this document was developed to bring order to the workshop sequence. Accordingly it would focus on those areas that were most disparate among the faculty members. A similar, more comprehensive, but wholly unsubstantiated document was written by a Systems Design Engineering student. [213] This document was written slightly before, and in response to, the reduction in the number of workshops that took place in 1991. The goals, conclusions, and recommendations of this document are duplicated in appendix F.

Systems Design Engineering students, along with some faculty members, also raised the issue of the qualifications of the faculty members teaching design and supervising the workshop.

> "From the beginning one of the basic issues in the department has always been the dichotomy between analysis and design. One of the most concise statements we have heard concerning this issue was presented by Professor Seeley. To paraphrase, he feels that integrated technical designs requires integrated technical analysis. Furthermore, to develop analysis techniques at the University level requires specialists. The students of Systems Design have often criticized the faculty of the department as lacking in design skills. From the above it can be seen that no other situation is possible. These analysts have hopefully produced skills from which at least a few designers will emerge." [237]

The workshops share a common difficulty with the comprehensive laboratories. In both cases there is a need for an engineering educator who has skill, experience, and the ability to teach synthesis and design. The experiences of the Department, for example through the fragmentation of the comprehensive laboratories, demonstrates that such individuals are extremely rare.

One discussion of the workshops describes them differently than do all of the other discussions.

> "You've three weeks to design a textbook for the Indians: that's a big assignment. But we don't think that you necessarily should insist upon perfection or high-quality results. What we're interested in doing is stretching the student-designer's mind." [211]

This perspective renders much of the criticism of the workshops moot. If the point of the workshop is to place the students in an untenable position so that they emerge changed, then it becomes impossible to say whether the workshops have met their mandate or not. There is no evidence to support or refute this position. The lack of formal evidence either way implies that the Systems Design Engineering faculty have not investigated the effectiveness of the workshops. Informally the evidence appears to suggest that the workshops are an effective tool for teaching design and stretching student minds. Students in Systems Design Engineering have enjoyed significant success at engineering competitions at the provincial and federal levels. In many cases their projects are based on their workshops. Superficially it would appear that the workshops do result in students who can design and implement innovative projects. However from personal experience as a coordinator for the University of Waterloo teams in 1999 and 2000, the students who entered the competitions had to invest significant time and resources towards enhancing their workshop projects. The basic workshop projects were seen by the students as insufficient to enter into the competitions.

Cohesion and integration

> "The Systems Design Engineering undergraduate curriculum is a reflection of the spectrum of interest of the faculty members of the department and their particular synthesis of an overall pedagogical philosophy of systems engineering education. Over the last decade, it has evolved from an amalgam of disparate disciplines into a fully integrated curriculum which covers a broad spectrum with a unified systems engineering viewpoint." [208]

It is difficult to demonstrate that the curriculum, research, and vision within the Department of Systems Design Engineering are cohesive and integrated. Evidence of a lack of shared vision comes from the expansion documents and lack of shared definitions described earlier. From discussions with a number of faculty members, both new and old, neither of the documents described earlier that discuss the role of the workshop sequences were distributed to the faculty members. This lack of distribution implies a lack of interest on the part of the faculty in developing a shared vision of this essential aspect of the programme.

There is also evidence of an incoherent approach to the curriculum, and in particular to assessment. Fully one third of the document describing the workshop sequence focused on developing a common assessment regime. [8] The department has also produced a style manual for technical reports. [135] According to the author, one of his primary goals in writing the style guide was to ensure consistent grading across the faculty members. With respect to the curriculum, a lack of shared vision is evidenced by the wholesale changes in the content and goals of core courses when taught by different faculty members. [276, 41, 171] Such changes might be expected in elective courses. Given that the essential flavour of a department comes from its core courses, it is important that these courses exhibit consistency and a unity of purpose.

A lack of integration is also evident in the research publications produced by faculty members within the department. The department periodically publishes a brochure that describes its graduates studies and research programmes. [77, 70, 81, 71, 69, 72] Those brochures that list research publications reference approximately 140 journal articles and books. Of these publications no more than eight include as co-author(s) faculty members from within the department. Of these eight, at most one involves faculty members from different research groups. Unfortunately it is not possible to determine whether the co-authors from outside of Systems Design Engineering come from different backgrounds than the primary authors from within the department.

The department has been described as having a unified systems engineering viewpoint. [208] This viewpoint was considered sufficiently different from that of other engineers that it became the basis for creating a new department in which to explore its ramifications. At the same time the department describes itself as being interdisciplinary. The breadth of the research undertaken within the department is a testament to its interdisciplinary nature. These two factors should lead to research papers involving multiple members of the department. That such papers have not been published speaks to a lack of internal cohesion and integration that belies these descriptions of the department.

The current chair of Systems Design Engineering has acknowledged that the department is lacking cohesion and integration.

> "Hearing through [George Soulis'] words the energy, enthusiasm and creativity, the sense of missions and common purpose that our department grew out of has renewed my desire to nurture and further that enterprise... I intend to work as chair to restore that sense of community and common purpose, to help current and new faculty acquire a sense of ownership and personal commitment to educating systems design engineers, and to encourage and support their individual and collaborative scholarship... My most important contribution to building the sense of community I envision will be to do what I can to engage everyone in the department in formulating our agenda, to value and appreciate their contributions, and to support their initiative and hear their concerns." [152]

He has also presented his view on how to enhance the sense of cohesion and integration within the department.

> "When our newer faculty members begin to have a sense of ownership in this vision and sense of their own contributions, both within their individual discipline and to the broader methodological framework, their own and the department's direction emerges." [152]

At present there is little evidence that the chair has been able the implement his approach to enhancing the sense of community vision among the faculty.

The systems approach

> "When we first entered Systems we learned about the wonders of the systems approach, systems concepts, systems engineering, systems modelling, and general systems theory. Wow! You couldn't even define systems' because it was so immense and state-of-the-art! But then systems' disappeared as we were trained in the things every engineer should know (and then some)." [237]

> "It was not clear any more [by 4^{th} year] whether anybody in the class was learning or practising systems. But then systems had become very subtle. Most were applying systems design methodology and some mathematical systems tools both in their work and in their courses." [239]

> "If a 'systems approach' is to become more than an easily accepted but somewhat irritating concept, there is a need for expressions of it which eliminate any difference between what it is and how we may use it; the need is for accounts of systems-based *methodologies* which describe a systems approach as a way of analysing and hence trying to solve real-world problems." [42]

As discussed earlier there are no shared definitions of the systems approach in the literature produced by the Department of Systems Design Engineering. The literature does include a sizeable number of terms prefixed by 'system(s)'. These terms, and a subset of the documents that use them, include:

- Systems perspective [152]
- Systems philosophy [152]
- Systems point of view [252]
- System analysis [253]
- Systems behaviour [50]
- Systems study [128]
- Systems design [236]
- Systems methodology [81]
- Systems theory [74]

Of the documents located during this research only one provides an explicit definition for its chosen term. An internal letter sent in 1989 provides a complete definition of the term 'systems approach'. [128] The systems approach is defined as:

- Formulate the problem
- Gather and evaluate information
- Develop potential solutions
- Evaluate workable solution
- Decide on the "best" solution
- Communicate the systems solution
- Implement the solution
- Establish performance standards

This description is almost identical to the engineering design process described in many introductory engineering textbooks. [210, 91, 93, 95, for example] This similarity is of some concern as it implies that the core approach of the department is not as 'unique'[14] as its descriptions imply. [235, 249, 159, 237] As there are so many other terms used to describe the key aspects of the department, the lack of distinction of this definition may not be a great concern. What is clear is that the faculty members feel that there is something related to the concept of a system that defines the department. It is also clear from their yearbook comments that the students within the department are not sure what that something is.

There is an organized community devoted to the study of systems. This community has experienced some of the same fragmentation as the Department of Systems Design Engineering (see section 6.12.6). However in spite of its fragmentation, the systems community

[14] The descriptions do not define the term 'unique'. Based on the available documentation, all that can be said with certainty is that within North America there are no other accredited engineering programmes with the name *Systems Design Engineering* (see appendix E).

has been able to rally around a number of key researchers, concepts, and methodologies. During 1970s the Department of Systems Design Engineering incorporated the works of such systems researchers as Checkland, Ackoff, and Jenkins into portions of its undergraduate curriculum. [50] Systems materials, such as articles from *Systems Behaviour* and a series of texts produced by the Open University, were also used. [50, 232] Starting in the 1980s, and continuing to the present, the department has severed its ties with the systems community. The courses, such as SD161, that used to teach the ideas of the systems community changed instructors. The new instructors chose to cease using materials from the systems community. [276, 41, 171] Currently there appear to be no undergraduate courses in Systems Design Engineering that leverage the materials available from the systems community. The only current course in the department that advertises itself as doing so is *SD761 The Epistemology of Systems Thinking*. [155] This course is intended for graduate students, although starting in 1999 a small number of undergraduate students have been permitted to attend.

The difficulty in maintaining the links to the systems community is due in part to the attitudes of faculty members who are new to the department.

> "...think about what it was that attracted me to Systems Design Engineering and to think about the balance of my career. I continue to value the department for its interdisciplinary and innovative program which allows me an intellectual breadth in both my research and my teaching. [152]

Similarly, during a presentation to a first year class in 2000, a new faculty member was asked "How do you use the systems approach in your research and how does this make you different from other researchers in your discipline?" His reply, paraphrased, was "I do not know what the systems approach is. I do not use the systems approach in my research." He continued with the comment, similar to that quoted above, that he had joined the department "because it allows me the flexibility to pursue my interests." While there is no evidence that these two quotes represent the views of the faculty in general, there is no evidence to say that they do not. This lack of evidence implies that faculty members within the department have not seen fit to share their views on the department with a wide audience.

In many ways, all that is left of the original Systems Design Engineering is a stellar reputation for excellence and a flexible undergraduate curriculum. The visions of the founders have fallen to the wayside as faculty hired to bolster specific research areas have been unwilling, unable, or unasked to adopt them. Most alarming is that there appears to be no desire on the part of the Department to pursue these issues. Recent discussion of the future of the Department made no mention of design or systems[15]. Instead the focus was on expansion or partnering with other departments. As opposed to leading the resurgent interest in systems, design, and complexity, the Department shows signs of fading into the background. In essence Systems Design Engineering has had a 30 year head start on the remainder of the engineering education community. It is the only department in North America that has any significant experience integrating systems and design into the undergraduate engineering curriculum.

5.2 Related initiatives

> "Within the Canadian University scene, the question has often been asked whether some other schools also should start departments of Systems Design. Since the department grew out of the particular set of circumstances prevailing within the faculty, there is no simple answer to this question. However there is no doubt about the need for a systems engineering programme. As the complexity of systems increases, as will never cease to happen, a good systems education with a proper balance between the systems and design aspects becomes all the more germane. This viewpoint should be an integral part of all engineering education and not just that of systems engineering." [160]

[15] A possible explanation for this omission is that the ideas of systems and design permeate all aspects of the department. Accordingly there would be no need to mention then explicitly. Given that the expansion documents mention explicitly the department's mission and "sense of community", both of which could also be considered to permeate the department, this explanation does not appear to be valid. [26, 27]

5.2.1 Past and present

It is impossible to assess with any certainty the uniqueness or impact of the Systems Design Engineering approach to engineering and to engineering education. Since the Department was founded an engineering speciality called Systems Engineering has been accepted into the engineering fraternity. At one level both the names and the focuses of the two disciplines are very similar. The International Council on Systems Engineering (INCOSE) recently described Systems Engineering as follows:

> **Systems Engineering** An interdisciplinary approach and means to enable the realization of successful systems.
>
> **System** An interacting combination of elements, viewed in relation to function.
>
> – INCOSE Winter Workshop, January 1996

This description is similar to the high level description of Systems Design Engineering. However as with Systems Design Engineering once the focus shifts to implementing this vision the result is very different.

> "Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem:
>
> - Operations
> - Performance
> - Test
> - Manufacturing
> - Cost & Schedule
> - Training & Support
> - Disposal
>
> Systems Engineering integrates all the disciplines and speciality groups into a team effort forming a structured development process that proceeds from concept to production to operation. Systems Engineering considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs."

This description, which is the one given primacy on the INCOSE web site, presents a very different approach to engineering than that promoted by Systems Design Engineering. [148] This vision of Systems Engineering is more accurately described as "life cycle engineering". The attention to transdisciplinary techniques and the focus on design morphology are conspicuously absent. Interestingly the history of the Systems Engineering discipline is complementary to the experiences of Systems Design Engineering. Systems Design Engineering began with a vision of breadth and synthesis and evolved into a more focused, less generic idea. Systems Engineering began with the notion of life cycles and engineering systems and is trying to expand to address general systems. The slow pace of adoption of these more general principles in Systems Engineering education is a testament to the difficulties experienced by Systems Design Engineering.

Appendix E lists all of the accredited engineering programmes that appear to have embraced systems concepts to some extent. These programmes can be grouped into two broad categories. The first are those that have added the term 'system' to their name but do not present themselves using the terms associated with the systems disciplines. Such programmes have names such as "Biological Systems Engineering" and "Computer Systems Engineering" and "Industrial and Systems Engineering". A random sample of 10 of the 27 engineering programmes accredited under these names revealed that none of them either describe themselves in systems terms or offer courses that cover systems concepts. [60, 20, 59, 61, 64, 218, 46, 146, 104, 147] Given that accreditation requires that programmes with similar names have both similar curriculum and similar definitions the results of this sample can be extrapolated to the larger group.

The second broad grouping of accredited "systems" programmes are those who have adopted the INCOSE definition of systems engineering. [102, 101, 62, 100, 63, 82, 241, 96, 67, 65, 66, 231, 273, 272] As with the current Systems Design Engineering their primary attributes appear to be the breadth of their curriculum and the flexibility they allow their students. Of the 11 accredited systems engineering programmes only two offer courses that cover systems concepts. [62, 82] Both institutions offer a single course covering this material. At present in the United States and Canada no programme, including Systems Design Engineering, offers an accredited engineering programme equivalent in vision and successful implementation to that offered by Systems Design Engineering at the University of Waterloo between 1981 and 1991.

5.2.2 Proposed

Systems Design Engineering was the response of a small group of engineers to flaws they saw in engineering and engineering education. What they saw in the late 1960s is only now being acknowledged by other engineering educators.

In 1998 the Massachusetts Institute of Technology created the Engineering Systems Division (ESD). The goal expressed for ESD is similar to that of the founders of Systems Design Engineering.

> "To solve 21st century problems, engineers need frameworks and methodologies that view technology as part of a larger societal whole. ESD develops academic and research programmes that reflect the integrative aspects of engineering, complement traditional engineering science strengths, and enable students to better understand complex engineering systems." [176]

A graduate programme in ESD was created immediately by merging a number of existing graduate programmes. During the last 3 years the ESD has attempted to operationalize this vision at the undergraduate level. So far they have been unable to articulate any coherent or cohesive vision for their undergraduate programme. [229, for example]

The University of Toronto recently struck a task force on curriculum change. The goals for this task force are in large part taken from the CAE report *The Evolution of Engineering Education in Canada*.[29] The task force goals are:

- broaden the engineering education
- more flexible programmes, options of multiple degrees
- more emphasis on design

The preliminary results of this task force read almost identically to the steady state design adopted by Systems Design Engineering. For example:

- integration of knowledge from different courses
- design in first, second, and fourth year

- full fourth year capstone design project
- more flexibility in the senior years
- third and fourth year driven by prerequisites for advanced studies
- fast tracking to dual Bachelor or Master's degrees
- more complementary studies study

Whether the University of Toronto can avoid the problems encountered by Systems Design Engineering remains to be seen.

5.3 Conclusions

Systems Design Engineering was 30 years ahead of its time. Aspects of its curriculum, such as increased flexibility, and workshops, have slowly but steadily become part of the education of all engineers. Linking the concepts of systems and complexity to engineering remains a niche approach. However the number of departments trying to occupy that niche is slowly growing. This growth will accelerate as funding for research into these areas is increased.

Discussion of any failures on the part of Systems Design to live up to its plans must consider the environment in which the department was designed and has evolved. The constraints placed on the department by the faculty of engineering and by the lack of available resources, restricted the innovations that could be implemented. The need for substantive compatibility with traditional engineering programmes kept the department from exercising the creativity it needed to implement its visions. That having been said, there is no evidence that the department has ever mounted a sustained campaign to alter its environment to suit its needs. The broader environment was also unable to supply the faculty or the pedagogical innovations required to teach the topics of systems, complexity, and design. This is not surprising because no other departments were teaching the required skills to their students. Teaching these topics requires skills and techniques that to this day remain undeveloped.

However, the combination of environment and resources together does not explain the largest failing within Systems Design. The lack of a cohesive[16] vision within the department

[16]The term 'cohesive' is used, as opposed to similar terms such as 'shared', 'common', or 'consensual'.

has kept it from realizing its full potential. Fragmentation of the vision has led to a balkanized department that is a shadow of both its former myth and its design potential. Recently INCOSE created an Ontario chapter.[17] The current chair of Systems Design Engineering has already expressed a desire to incorporate aspects of INCOSE into the graduate programme. [152] Given the lack of a shared, coherent vision of the systems aspects of Systems Design Engineering, it is likely that the department will soon regress into more than a standard department of systems engineering. Whether ESD and the University of Toronto can avoid the fate of Systems Design remains to be seen. The poor showing of the early attempts of the ESD faculty to meld their disparate programmes together do not bode well for their attempt.

All of these other terms carry with them the connotation of a single vision that must be adopted, without change, by all faculty members. This unity is not required for the vision to be a valuable, stabilizing force. It is sufficient for the different visions to be able to interact within a common frame of reference.

[17]From an email dated September 27, 2001: *Why a Southern Ontario Chapter of INCOSE?* A group of professionals working in Southern Ontario saw the need for a local group where they could exchange ideas on how to develop complex systems, and tap into the larger body of knowledge and techniques collected by INCOSE. *Who should attend?* If your work involves developing systems or products involving multiple disciplines or industries: mechanical, electrical, software, transportation, communication, medical, information systems etc. If you perform one of the following roles: system requirements definition, system analysis, system design, product development, software development, or project management of systems development.

Chapter 6

Proposals, prognostications, and visions

This chapter provides a vision for the future of engineering education. It is predicated on the belief that engineering education, both as a system and as a component of the wider social system, has lost its way. Thankfully both policy makers and engineering educators are aware that engineering education must change. Unfortunately there is little evidence that either group will be either willing or able to envision significant changes to the current system. [55, 173, 140, for example and in addition to this thesis]

As much as possible, the vision presented in this chapter is influenced by the current state of engineering education. However, the vision goes beyond the previously identified gaps by synthesizing this information with other sources. A number of the points raised in this chapter, in particular those in sections 6.10 and 6.11, are presented in a purposefully controversial style. A key conclusion of this thesis is that discussions of engineering education have to move beyond stock ideas and broad complaints. Deliberate provocation is one mechanism to accomplish this goal.

The content in this chapter is not held to the same standards of substantiation as the previous chapters. This content is a response, written in a similar style, to the major reports on engineering education. [31, 28, 48, 29] Accordingly this chapter presents an informed, yet largely unsubstantiated vision for the future of engineering education. Implicit throughout this chapter is the assertion that a research programme must be developed to substantiate or refute the various claims.

6.1 The world is not going to slow down or get simpler

The world is becoming an exceedingly complicated place. The rate of change of technology and social organization and the volume and pace of information transfer are accelerating. This situation offers enormous opportunities but may be overwhelming for many.

Thomas Homer-Dixon's *The Ingenuity Gap* is one of many books that attempt to address this concern. Unlike many others, it attempts to incorporate systems theory and complexity into its discussions (see section 6.12). [142] During a presentation given at the University of Waterloo, Homer-Dixon summarized the current situation as follows.

> "Consider a car driving through the mountains. The windows of the car are painted black. The brakes don't work. One person is steering while another works the accelerator. The road is very twisty and there is no guardrail."

The *The Ingenuity Gap* proposes three responses. First, the pace of life must slow down. Second, the world must be simplified. Third, ingenuity must be developed. Unfortunately, there is no evidence that these responses can be implemented in an effective manner.

James Burke, author of *The Day the Universe Changed*, makes a compelling case that every new communication device, from inscriptions on animal bone to wireless messaging, accelerated change and created complexity. [25, "Matter of Fact"]

Communication brings with it conflicts between beliefs and new information. In response to the new information an individual can choose either to modify his or her beliefs or to ignore the new information. The eventual decision will depend on the nature of the information and the individual. Factors such as the perceived value and reliability of the information and the mental and physical states of the individual may contribute to the decision. As people are exposed to more information faster, they sometimes become overloaded and may ignore, discard, or misinterpret the new information.

However, communication technologies also offer tremendous opportunities. Computer programmers in Bulgaria, highly educated but limited by Soviet technologies two orders of magnitude slower than the top of the line, were connected to the global communications network and soon proved themselves to be among the global programming elite. [279, 145] The Open source software movement is predicated on the notion that given sufficient code reviewers, all bugs are shallow. Therefore, the accomplishments of the Open Source movement, that has developed software of superior quality to that of commercial vendors, are only possible because of the communications network[1]. The same communication network and tools that facilitate software development have been used to effect political change. The failure of the Multilateral Agreement on Investment (MAI) has been attributed to the ability of activist groups in a number of countries to share, and possibly to distort, the information made available by different governments around the world. The human potential that might be liberated and shared by the global communications network is immense. But these possibilities will be purchased at the cost of increased complexity.

These problems and opportunities are probably going to grow in the future. Communication technologies are both adaptable and autocatalytic. So long as there is any desire for communication, it is possible to develop improved communication mechanisms. Each communication mechanism facilitates the development of its successor. This autocatalysis is most evident in the field of computer networking protocols. Once the first computers were networked, those involved were able to collaborate using the network to develop protocols that better met their needs. At present the number of special-purpose protocols is increasing at an ever faster rate because of the added communication and collaboration potential each technology offers. Over time the reach of a communications network can only grow. Once basic communications have been established the autocatalytic effects emerge.

6.2 Our collective physical survival requires a new kind of engineering

Engineering at one time dealt primarily with immediate essentials such as clean water and shelter. As the ability to address these problems has in large part been developed,

[1] A valid criticism of Open Source software is that is it designed by and for technical sophisticates and accordingly is not suitable for typical users. The validity of this criticism is being eroded as more individuals with experience and interests in human factors and usability join the network.

engineering is now being asked to address problems that relate to the of quality of life, in addition to maintaining all of the essentials. In the first case the problems are simple and the criteria for success universal. In the second case the problems are complex with multiple, often conflicting, objectives. Engineering has found itself incapable of dealing with these complex, uncertain issues with the same efficacy as it dealt with the earlier simpler issues. [14] This is particularly true in the context of long term environmental change.

It is undeniable that humans have the ability to effect long-term change on the biophysical environment. Thus far those who control and are responsible for many of effects have been able to insulate themselves from the impacts. This ability to remain insulated is fast being eroded. From the respiratory effects of ground-level ozone to the hermaphroditic effects of oestrogen analogues, humans are becoming increasingly aware of the consequences of their actions on the biophysical world. [18, 244]

Our society has a number of long term choices with respect to how it will interface with the biophysical world. One choice is to learn to control the biophysical world. This approach is similar to that attempted by the BioSphere projects, in which ostensibly controlled biophysical environments were designed. This approach has thus far been unsuccessful [98] A second choice is to minimize the extent to which humans interact with and are affected by the biophysical world. Possible examples include air conditioning and the research into genetic changes that would reduce human susceptibility to melanoma. A third choice is to learn to understand the biosphere and coexist sustainably. In all likelihood, all of the choices will be pursued simultaneously and in concert.

Regardless of the approach, an improved mechanism for understanding and interfacing with biophysical systems is required. The social role of interfacing between the social and the biophysical worlds has been assigned to the engineer. Questions of scale do come into play. Many individuals are willing, and able, to effect small-scale change. For example they may build a deck or discard a plastic wrapper. While the cumulative effects of these individuals is large, the effort required to dissuade them can be disproportionately small[2].

[2]The studies done in New York City support this assertion. A clean and unvandalized location would remain so for as long as the littering and graffiti was minimal. Once a critical point was reached the location would degrade extremely quickly. Fixing a single broken window pane or removing a small amount of graffiti was sufficient to discourage further acts of vandalism. [277, 157] The Toronto Transit

By contrast, the individual and cumulative effects of engineering are significant. Whether they believe so or not (see section 6.12) accountably and responsibly interfacing between the social and the biophysical worlds has always been, and will continue to be, the social purpose that legitimizes and defines the engineering profession.

Historically, the interface embodied by the engineer has been unidirectional. Society, through political and economic decisions, decided on a particular biophysical intervention. Engineers were then responsible for its design and implementation. While this model of engineering may appear simplistic, many of the major engineering developments of the modern era were developed in this manner. As a consulting engineer on the Aswan dam project observed:

> "When I studied engineering, dam building was presented as a rational process, but most dam building is driven by greed, or a dictator who wants a project." [154, quoting Jobin]

Similar concerns can be voiced regarding the development of physical artefacts intended for human use. Again the engineer was expected to design and implement the physical artefact based on the specifications developed by management. Many of the artefacts cited by Donald Norman, as examples of designs poorly suited to their users' needs, were developed under this regime. [186]

> "Human interplay with the environment can be felt as an integral part of a dynamic system held in delicate balanced order, an outlook involving a change in consciousness and a flood of observations. The universe is a place of constant conversation between animal populations." [136]

It is clear is that the interface between the social and the biophysical worlds must become bidirectional. As the primary embodiment of this interface, the responsibility for developing the tools, techniques, and ethics to support this enhanced role falls to the engineer. However the engineer will be unsuccessful in assuming this role unless all members of society have some awareness of the need and techniques for bidirectional communication between the social and the biophysical worlds. The engineer will lead this initiative, but society as a whole must participate.

Commission has used this approach in their anti-littering messages to their riders.

To a limited degree the development of a bidirectional linkage between the social and the biophysical worlds this has begun. Engineering methodologies, such as user-centred design, have been developed to promote a bidirectional flow of information. Engineers are also active in the environmental impact assessments used to evaluate existing and potential projects.

> "Dams achieved exactly what the planners and engineers intended–interrupting large annual changes in stream flows so water would be available all year. Now we look at those realized intentions as negative consequences. But there have been unforeseen benefits in the environment, too: an increase in food and habitat for raptors, trout fisheries. Dams are here now; the issue is how to use them." [154, quoting Floyd]

These promising changes remain the exception. This is not surprising given that engineers do not often have the power within their organization to achieve bidirectional communication and engineering graduates are not prepared for this role. Jobin noted that engineering education does not address the non-technical issues that drive many engineering projects.

6.3 Our collective social survival requires abstraction and reflexion

Many of the discussions of modern life address the phenomenon of information overload. The theme of information overload is central to *The Ingenuity Gap* and to Brown and Duguid's acclaimed *The Social Life of Information*. [142, 21] An underlying tenet of a number of prominent self-improvement schemes, for example *The 7 Habits of Highly Effective People*, is the management of information. Within engineering education, the desire to avoid information overload is cited as the primary cause of the "breadth vs. depth" debates that dominate curriculum discussions.

There are three mechanisms to cope with information overload. The first is to slow the information stream. As described in section 6.1 the increasing density of communication links makes this approach difficult. Social and economic pressures make disconnecting from the communication networks almost impossible[3]. The second mechanism is to prioritize the information and deal only with that of high priority. This mechanism, described as "Put first things first" is the third of *The 7 Habits of Highly Effective People*. [53] Issues of connectedness and complexity (see section 6.12.7) render simple prioritization schemes ineffective, if not impossible. The third mechanism to cope with information overload is abstraction. Abstraction differs from prioritization in that it is a shift of perspective, not an ordering within a given perspective.

Abstraction has already been adopted in the business community as a means to address information overload. According to firsthand reports from colleagues, students in MBA schools are taught that there are only two differences between Chief Executive Officers (CEOs) and Line Managers (LMs). The first is responsibility. When a CEO makes a mistake the entire company suffers, whereas an LM mistake is likely to affect a much smaller group. The other difference is abstraction. Where the LM deals with individual employees the CEO deals with divisions represented by directors. The management techniques are the same. The CEO should not, and in all but exceptional cases cannot, use the same level of abstraction as the LM. The cognitive demands of management without abstraction are simply too great.

The computing programming field demonstrates the validity of this approach to reinterpreting information overload. Today there are hundreds of different computer programming languages. New languages are developed and adopted at a rapid pace. Programming languages also tend to disappear slowly. There are still many systems in use developed using early programming languages. At the *syntax* level of abstraction the rate of development of new programming languages has been large. However, at the *conceptual* or *cognitive* level of abstraction there have been few changes. Table 6.1 presents one view of the evolution of the conceptual approaches to programming[4]. For each conceptual approach a number of implementation languages are given. Good programmers can function within multiple syntaxes. The best programmers, especially when dealing with design and architectural

[3]Discussions with peers have revealed that, in a growing number of technology-focused workplaces, turning off a pager or a cellphone is grounds for dismissal.

[4]The evolution of computer programming is a "holy war" issue, much like preferred editors and operating systems.

Cognitive Approach	**Hallmarks**	**Implementations**
Machine language	Bit-level representations of internal components	8086, 6802
Assembler	Disorganized, symbolic representation of machine language; bytes (aggregates of bits); spaghetti (disorganized comparisons and jumps)	MASM
Structured	Formally organized, symbolic representations of machine language in human language terms; data types (numbers, characters); looping constructs (FOR,REPEAT,WHILE)	COBOL, FORTRAN, BASIC
Stack	Lambda calculus	Forth, Scheme
Procedural	Subroutines; separation of storage and algorithms; structured, user-defined data types	Algol, C, Pascal, Perl
Imperative	Formal logic and schemas	Prolog
Object-Oriented	Integration of algorithm and data; modelling and simulation	Smalltalk, Simula, C++, Java, Modula, Python, Ruby, Oberon

Table 6.1: Abstractions within computer programming

issues, are those who can function within multiple conceptual schemes.[5]

A key point is that survival in a rapidly changing complex world does not require always operating at the most abstract level possible. In software development, as in most human endeavours, at some point design must give way to implementation. Most endeavours have

[5] In the contemporary open source software movement such individuals include Larry Wall (the creator of PERL), Guido van Rossum (the creator of Python), and Miguel de Icaca (the creator of GNOME). Based on their books and white papers, each of these individuals used multiple conceptual schemes while developing their respective, highly respected products. [264, 260, 58]

developed tools, such as software compilers or project management tools like PERT charts, that lessen the burden of implementation. Some engineering researchers has gone so far as to attempt to automate the design process in its entirety[6]. In most cases these tools cannot handle the implementation independently and require some human intervention at a lower level of abstraction. It is unlikely that this requirement will ever be removed.

The notion of shifting levels of abstraction renders the "breadth vs. depth" argument found in much of higher education moot. The goal is no longer to teach to a point $(d_{optimal}, b_{optimal})$ in the $depth \times breadth$ space. Instead, the goal should be to develop individuals who can recognize the appropriate level of abstraction and are comfortable working at different levels of abstraction. Different individuals will prefer different regions within the $depth \times breadth$ space.

Conscious abstraction must be supplemented with reflexion. Among the benefits of abstraction there are also risks. Abstraction can be an escape from consequences. In war, abstraction allows officers to give orders without acknowledging the human costs. As described in sections 6.1 and 6.2, individuals, especially engineers, are being empowered to change society and the biophysical world in amazing ways. Peter Parker, the Amazing Spiderman, observed "With great power comes great responsibility." Reflexion creates opportunities to reflect on the moral and ethical aspects of the abstracted concerns.

Reflexion also promotes a deeper understanding of engineering tools and techniques. Many of those who interact with technological tools are not aware of the assumptions and theories that allow those tools to function. This is especially true in fields such as software development. Jackson has published a number of papers in the field of management science describing the negative consequences of merging techniques without regards for their theoretical underpinnings. [150, for example] Similar problems are encountered at the level of simple terminology. Two groups that use the same term, for example *equilibrium*, with different meanings will have difficulty interacting in meaningful ways.

This discussion is not meant to imply that we must always focus on theory at the expense of experience or practice. Nor does it seek to develop single definitions or approaches. Instead this discussion calls for engineers to develop the ability to move seamlessly between

[6] *Artificial Intelligence for Engineering Design, Analysis and Manufacturing* (AIEDAM) is a journal devoted exclusively to this topic.

theory and practice, always informed by reflexion. This ability, coupled with the ability to move between levels of abstraction, is required to address the world that is coming into being.

6.4 Higher education in universities will endure

The imminent demise of the current university system appears nigh. In the popular media the reasons for this demise are numerous and include:

- Professors and classrooms will be made irrelevant by online learning tools
- Research will move into private labs
- Learning will become a lifelong individual pursuit with no need for universities
- Colleges and trade schools, not universities, provide the skills needed by industry

The media pundits completely miss the point of higher education and are unaware of the history of higher education in North America. Their predictions in the areas of skill-based and online learning, are fundamentally no different than the predictions made between 1880 and 1930 in the United States. During this period correspondence programs, first operated by the private sector and later by the universities, became exceedingly popular. By 1940 the correspondence programs had been discredited and all but destroyed. Noble, in a series of papers titled *Digital Diploma Mills*, presents a scathing deconstruction of the current vogue in computer-mediated distance learning based on these turn of the century experiences. [182, 183, 184, 182, 185]

Universities are not about training or research. Universities develop citizens. As will be discussed further in section 6.13 university education takes place during the particular phase of life in which the values of childhood are assessed. The university environment provides new information and a heterogeneous community, which both inform these changes. The marketable skills that are developed are a side effect, not a goal, of the university experience. Given this interpretation of the role of universities, it is clear that the institutions will not be replaced by technologies that focus on the transmission of skills. It must be emphasized that there are multiple paths that can be taken to become a citizen. The university path is distinguished only by being relatively straightforward and socially acknowledged.

Even if the acquisition of skills is perceived as being the primary goal of university education, there is still evidence that universities will endure. The underlying tenet of *The Social Life of Information* is that information is best understood in its social context. [21] People simply learn better when in the company of other people in the places where the information is actually used. Techniques such as "teach the teacher", 3-day intensive seminars, and online simulations of physical experiments have all been shown to be less effective than traditional forms of education. Quality education takes time and requires the physical proximity of others. Even the Open University, considered proof that distance learning can supplant traditional universities, acknowledges that learning requires face-to-face contact. Its system of education melds distance learning approaches with satellite campuses and local seminar groups.

6.5 A philosophical vision of higher education

A new vision for university-based higher education can be developed based on the purposes described in section 6.4. This vision acknowledges that the role of higher education in North America is to enable individuals to act within a social system that values both the individual and the group. This vision is influenced by the cognitive model developed by Perry. Perry's model is depicted in figure 6.1. [57] Perry's model was developed by tracking cognitive changes in undergraduate students as they progressed through their programme. Students began with a strong commitment to a single perspective. As they progressed and were exposed to new perspectives their commitment to any given perspective lessened. By stage 5 of the model, the students cognitive state had degenerated into relativistic paralysis where they were unable to commit to any perspective. The remaining stages of the model depict individuals making conscious commitments to a perspective or set of perspectives. Throughout their development, the students' reliance on authority figures diminished.

The philosophical vision of higher education does not allow a student to begin discipline-specific instruction until they have attained stage 5 of Perry's model. To reach this stage students are exposed to two categories of experiences. The philosophical nature of this vision comes from the emphasis in both categories on reflexion, abstraction, and meta-level discussions. As will be discussed in section 6.13 this vision can only be realized

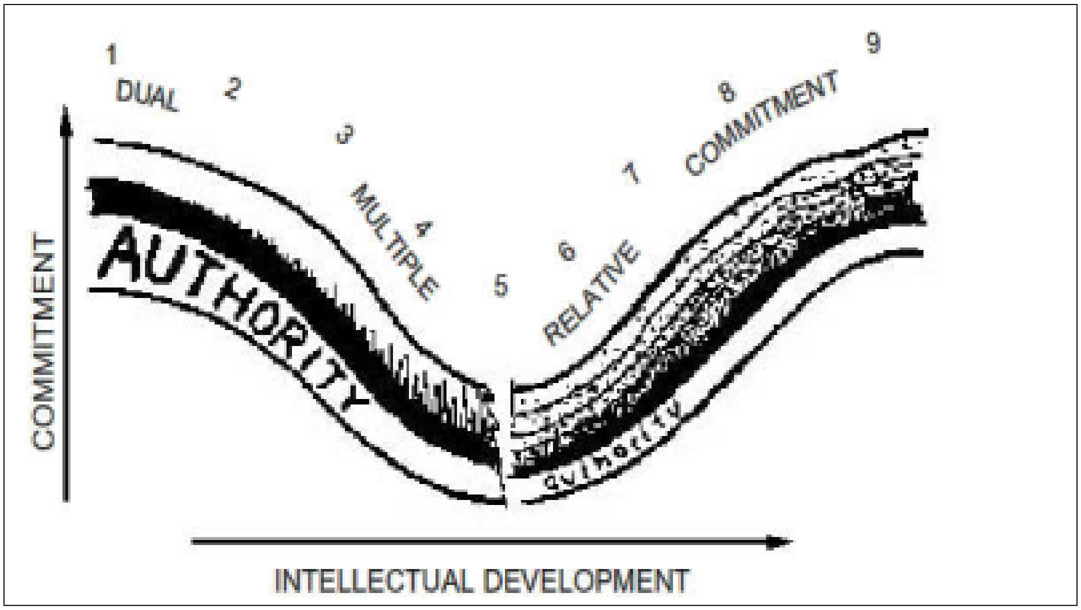

Figure 6.1: Perry's model of cognitive development

effectively in the university setting.

> "Since every individual is accountable ultimately to the self, the formation of that self demands our utmost care and attention." [138]

The individualistic aspects of North American culture lead to the need for individual accountability and development. All of the experiences described here are intended to introduce the student to new ways of being and knowing, in preparation for a conscious commitment to their own path. At no time during this phase of their education is the student expected to adopt any particular position.

> "The objects of our palpable sense experience can be influenced by choice both conscious choice and unconscious. This is a demonstrated fact that does not require that we believe some force within us reaches out and touches the universe. I address a pragmatic relationship between belief and what we identify as 'real.' All of our judgements carry a heavy burden of belief. It is not enough

> that we are aware of this and guard against it. Alternative interpretations must always receive our attention." [137]

Students must be actively discouraged from adopting fixed positions in order to encourage them to develop cognitively. This discouragement must be in the form of new experiences not in the form of prohibition.

I believe that there are four areas that students must discover at this stage of higher education. The first is beliefs.

> "In an indeterminate universe, belief is a dominant force. Beliefs order the unfolding of events. If enough of us believe, a new thing can be made to exist. Belief structure creates a filter through which chaos is sifted into order." [137]

Experiences that deal with beliefs include exposures to different ontologies, epistemologies, metaphysics, and religions. The second area is ethics and morality. The third area of discovery is reason. Experiences that deal with reason include forms of logic and critical thinking. The final area that students must discover is personal development. Experiences that deal with personal development include theories of learning and cognition, meditation, and reflexion. These four areas prepare the student for independent learning. These areas must be enhanced with preparation for life as a member of a community.

The preceding sections have discussed at length the need for, if not the inevitability of, interactions among members of society. Given the heterogeneous nature of the North American society, members of this society must be aware of, and able to cope with, disparate means of interaction. Examples of the experiences that will support developing these abilities include semiotics, linguistics, modelling and rhetoric.

The philosophical vision of higher education treats specialization as a conscious, reflected choice to adopt a particular mode or modes of expression and interaction. The current system of higher education allows students to specialize without ensuring that they are aware of what specialization entails. Students are expected to take control of their academic careers in many cases without knowing the beliefs and assumption that underlie the various paths open to them. Students can be trusted neither to examine the paths in sufficient detail to make a reflected decision nor to examine the gamut of paths available to them. Under the philosophical vision of higher education students are permitted to specialize only after they have amassed sufficient experiences to progress to the relativism stage of cognitive development.

This vision of higher education does away with much of the distinction between *major's* and *honours* programs. A major's programme is not designed to promote the cognitive development of the student. Accordingly it has no place in university-based higher education. A major's degree, with its focus on the unreflected understanding of the techniques of a single discipline, can just as easily be obtained through distance education. The vision espoused here is an enhanced and expanded version of the vision that underlies the concept of an honours programme. From personal experience it must be noted that the current distinctions between a major's and an honours programme appears to be primarily in the amount of material covered. The ostensible goal of introducing more philosophical aspects of the material has been supplanted by the desire to incorporate more details.

At present this vision of higher education does not take into account the development of researchers. One view of the distinction between a master's and an honours programme is that the latter is intended for those who desire a career in academia. In my opinion the ability to do research is a skill that is a basic part of higher education. A researcher is therefore an educated individual whose context allows them the freedom to explore the topics of their choice with minimal fear of censorship or external control. This vision also assumes that moving the student through to stage five of Perry's model will not take place in secondary school. At present I believe that the techniques of pedagogy and andragogy (see section 6.13) are not sufficiently developed to allow everyone to progress to this stage by the end of secondary school. It is also possible, based on the work of being done with emerging adults (see section 6.13), that many students are not psychologically or physiologically capable of attaining this stage during their secondary school tenure. While it might be advantageous for universities if secondary schools would push their students to reach stage five, current circumstances imply that this is likely not an attainable goal.

6.6 A community vision of disciplines and professions

Section 6.8 will describe the engineering profession as having lost its way. This lack of direction stems from an inadequate conception of what it means to be a profession. In its *National Guidelines for Professional Engineering Practice in Canada*, the CCPE defines a profession as "a learned calling which requires advanced knowledge, understanding, and abilities gained from intensive and specialized education, training, and practical experience". Additional attributes of a professional include working only in an area of expertise, serving the public, maintaining continuing competence, and exercising discretion and judgement. This definition of a profession, while keeping with tradition, is not easily operationalized and is not influenced by social theory.

The distinction between a discipline and a profession is analogous to the distinction between a common-law couple and one that is legally married. In practice members of a discipline and a profession perform the same tasks, in the same way, under the same constraints, and subject to the same broad social rules. The difference is that a professional has made a public commitment to act according to the dictums of their chosen profession. This public commitment accords some modicum of increased social status at the cost of additional social constraints[7].

A new vision for disciplines and professions is that of a community that exhibits shared languages, texts, themes, and connections.

Language A community cannot exist without one or more shared languages. The languages include symbols, terms and rules with which to manipulate them. The language of the engineering community includes calculus, statistics, and the iron ring.

Texts Texts contain content expressed in the shared languages. Each text will embody a particular set of assumptions, goals and perspectives. The expression of the content will be shaped by the nature of the shared languages. The texts of engineering include thermodynamics and the mechanics of deformable solids.

Themes The common threads, woven through the texts, are the themes within the community. Themes include the goals, beliefs, and assumptions embodied by the texts. The themes both shape and are shaped by the texts. Common engineering themes include

[7]The constraints include taking personal and legal responsibility for their actions.

the goals of protecting the public and creating predictive models of physical phenomenon, and the assumption that predictive models are possible.

Connection A community can neither form nor remain remain intact if its members can not connect. The connections among engineers include shared titles and experiences. As with all social systems, the disciplinary community changes over time and different aspects can change at different rates. In general, themes change most slowly, followed by languages and connectivity. The texts change most quickly as new engineering models and techniques are developed.

6.7 A social vision of professional education

The model of higher education discussed in section 6.6 leads directly to a new vision for professional education. The key premise of this vision is that a profession is distinguished by a reliance on informed, reflected judgment.

While education is a lifelong process it does exhibit stages. With respect to professional education there must be a distinct choice made by the student to effect the transition from general to professional education. As discussed in sections 6.3 and 6.6, it is vital that this choice is rooted in reflection. Admission to professional education therefore requires that the applicant demonstrate first that they are aware of multiple ways of interacting with the world and second that they have made a reflected, conscious decision to adopt the perspectives of the professional community[8]. In keeping with the need for reflexion the applicant must also demonstrate that they are aware of themselves as learners.

The choice to enter into professional education, with the concomitant choice to adopt the perspective of that community, does not imply that the applicant must forsake all other approaches and perspectives. Instead the application is saying in effect "when dealing with this community, I will respect their traditions and beliefs." The applicant is not required

[8]Currently many schools of medicine, law, and education[9] require their applicants to have a prior undergraduate degree. Engineering has long differentiated itself from other professions by not requiring this preliminary degree. Attempts to introduce this scheme, for example through a "3+2" or "professional master's" approach, have thus far met with complete failure. [219] By not including this preliminary degree, engineering education is much more likely to become an indoctrination.

to adopt or accept these beliefs, only to respect them within the context of the professional community.

Within professional education, all assessment, including admission to the system, is acknowledged as a dynamic, social negotiation. In the same way that current engineering programs are able to negotiate with the CEAB, the students and their professors also negotiate shared meanings, definitions, and assessment mechanisms. Whether the education process incorporates intermediate stages or assessment depends on the community, but the final decision as to whether the student should be recognized as a member of the community is based solely on whether the applicant is able to convince members of the community that they deserve recognition. The mechanism used in the convincing could include assignments and exams but could also include debate, composition, film, or any other expressive medium accepted within the community and by its members.

Between admission to the programme of study and admission to the profession the student must learn the languages, texts, and themes of the discipline. It is assumed that the student is already aware of sufficient connections, through the process of gaining admission to the programme, to bootstrap the discovery of additional connections. As discussed in section 6.6, the languages and themes change most slowly. Accordingly they form the core of the professional education. Some texts must also be learned and it is the shared responsibility of the student and their professors to decide which texts are most appropriate given the needs of the student and the community. As with assessment, there are no fixed processes of teaching and learning used to communicate the languages, texts, and themes. The techniques are negotiated between the students and the professors.

6.8 Engineering has lost its way

In 1997 the Canadian Council of Professional Engineers (CCPE) released *A Vision for the Engineering Profession in Canada*. The task force that developed the report was charged with identifying issues "so vital to the well being of the profession that properly addressed, the profession will prosper and grow, but if ignored, will cause decline and progressive decay". The report focused on maintaining the professional aspect of engineering, including governance and licensing. The report did not address the social role of engineering or the need engineers have for abstraction and reflexion.

At a more tactical level the ability of the profession to self-regulate in a manner acceptable to society at large is in question. The questioning is in the form of "demand-side" legislation, conflicts with emerging disciplines, and a disturbing trend within litigation. [194, 167] Social safety issues, relating to water quality in particular, have prompted the government of Ontario to consider forcing the provincial licensing body to regulate certain non-engineering positions. Under the current regime the licensing body chooses who must or must not be licensed as a professional engineer. The proposed demand-side approach would fundamentally change the self-regulatory nature of the profession. The past decade has also witnessed the emergence of new disciplines that see themselves differently than they are seen by the engineering profession. For example, the individuals researching and using biotechnology see themselves as engineers while the profession does not. Conversely, some software programs are now seen as engineering by the profession but not by their members. Confusion over what constitutes engineering serves to weaken the profession. In litigation, professional engineering qualifications are considered a guarantee of quality work, less and less often. All of these changes are eroding the self regulatory aspects of the discipline.

To a large extent, the engineering profession has allowed itself to be defined by its educators. A civil engineer is someone who has graduated from a programme in civil engineering, has sufficient experience and has demonstrated sufficient ethical and legal knowledge to be admitted to the profession. Given that these requirements are common to all engineers, the only thing that differentiates a civil engineer from other engineers is the content of their programme. To comply with the CEAB criteria their programme had to be defined and controlled by professional civil engineering professors. When coupled with the fact that 11 of the 14 current members of the CEAB are academics, it is undeniable that academia controls the nature of the engineering disciplines. These academics in turn are restricted by the conventions of higher education. As the universities change, for example towards distance education, so will engineering.

Perhaps the most troubling aspect of the loss of direction within engineering is that the profession appears to be unwilling to discuss the nature of engineering. It is true that there have been many attempts to define engineering. It is also true that the organizations that ostensibly direct engineers have undertaken various visioning and strategic planning exercises. However, past activities are not a valid reason to limit discussion on these matters. As a social entity, engineering cannot afford to discourage reflexion. As the membership of the profession changes, the definition and role of engineering must be continuously revisited. Furthermore, these discussions should also be integrated into engineering education.

6.9 There must be a framework for discussions of engineering and engineering education

Ackoff, a prominent social systems researcher, is credited with coining the term 'mess'. [122] Messes have a number of common attributes.

- Multiple, interdependent problems
- Emergent aspects
- Ill-structured nature
- Multiple perspectives
- Strong resiliency
- No right answers

Engineering education and higher education are excellent examples of messy situations. The systems community has developed a number of techniques to deal with messy situations. These techniques include the Soft Systems Methodology (SSM) of Checkland, the "Designing Within" approach of Banathy, the Total Systems Intervention (TSI) of Jackson, and the work done by Gharajedaghi at the Industrial Management Institute. [43, 16, 112, 122] Banathy has devoted significant efforts to applying his techniques to the reform of higher education in the United States. His "designing within" is an approach to design that resonates with the visions of engineering and the engineering profession described in this chapter.

> "We can empower ourselves individually and collectively to do so by learning how to design. The 'designing within' approach is based on the assumption that to be authentic and sustainable human activity systems must be designed by those who are in it; who use them; and who are served by them. Design can not be legislated. It should not be bought from experts. If the privilege and responsibility for design is given away, others will take charge of our lives and the shape of our future.

Human systems design is *authentic* if it builds on the values and ideas of people in the system and of those who are served by the system. It should reflect their collective vision of humanity; it should make use of their individual and collective talents. Design is *sustainable* if it is accomplished by the creative participation of all people in the system. Such participation: (a) enables people to better understand their system and their role in it; (b) generates consensus among those who participate; and (c) ensures that people will take part more effectively and with a deeper level of commitment in the implementation of the design. I call the practitioners of the 'design within' approach *User Designers*. They understand that 'we are collectively the *king* and we collectively have responsibility for our system. Our salvation comes from within: the kingdom is within us.'

I label this fourth kind the 'ethical' approach to human systems design. It enables self-determination and respects the autonomy of the system. It is a self-guided and self-directed approach to the art and practice of designing/learning organizations. This approach is based on the understanding that we can take responsibility for designing our systems and that we should learn how to do it." [16]

Banathy would describe the other approaches for dealing with messy situations as "designing with". In these approaches the designer, whose primary role is that of facilitator, works with decision-makers to develop a shared design solution.

Unfortunately Banathy has met with little documented success in applying his approach to higher education. His books are often cited and their messages are supported by leaders within higher education but his approach has not been adopted successfully at any significant scale. There are no discussions of the reasons for this failure. A likely reason is that this approach is sufficiently different from the norm in higher education that prospective user designers are not capable of shifting into this new role. What is needed is to use a "designing with" technique to begin the transition towards "designing within". Of the "designing with" techniques SSM is the most mature in terms of resource materials and case studies.

The mess that is engineering education must be subjected to a facilitated SSM exercise.

The question is, which stakeholders should be invited to participate? The discussions in sections 6.11 and 6.10 imply that both industry and the current engineering education leadership must be allowed to participate in, but not direct, the process.

A potentially contentious issue is whether engineering students should participate in the SSM process. From one point of view, students will be subject to results of the exercise, and as such deserve to participate throughout. Students also bring to the discussion a perspective that has not been transformed through past engineering education. The alternative point of view considers students to be neither qualified nor interested in developing a complete, comprehensive view of engineering. By having neither significant academic nor employment experience, students are not capable of discussing engineering in any meaningful way. Regardless of the point of view, it is also difficult to determine who can, and should, represent the student perspective[10]. From personal experience members of ostensibly representative organizations, such as the Engineering Students Council of Ontario, tend to represent only a subset of engineering students. In spite of these difficulties my opinion is that students should participate in the SSM process. Engineering students are expected to take an active role in designing their academic and personal futures. Excluding them from the exercise of making sense of engineering and engineering education is simply not fair.

In order for the process to succeed, the participants have a demonstrated desire to participate in the discussions and they must be willing to explore alternatives to the current system. This thesis has identified such individuals in the engineer and engineering educators stakeholder groups. While these lists are guaranteed to be incomplete they provide a starting point for discussion.

6.9.1 Engineering educators

The individuals listed below are all engineering educators who have demonstrated a desire to go beyond the "summer vacation" investigations of engineering education. Each has made a significant contribution to the engineering education literature. Interestingly, almost without exception these individuals do not advertise their engineering education activities. Their online curriculum vitae and lists of research interests make little, if any,

[10] It is also questionable where there is a single student perspective. In all likelihood there are a multitude.

reference to their educational activities. These are the most recognized individuals in the field of engineering education and they are for the most part unwilling to advertise themselves as such.

Phillip Wankat is the co-author of *Teaching Engineering*, the only comprehensive resource available for engineering educators. [265] He is also the primary co-contributor to the *Teaching Toolbox* section of ASEE Prism. As author of the only meta-study on engineering education literature, he has demonstrated a desire to inject formal research techniques into the study of engineering education. [266] He is a chemical engineer[11]

Frank Oreovicz co-authors with Wankat. He is a chemical engineer.

Donald Woods is a Canadian engineering professor who recently retired from McMaster. He has pioneered the use of Problem Based Learning in undergraduate engineering education. With Felder and Stice he has authored a number of papers describing the future of engineering education. He is a chemical engineer.

Richard Felder is one of the few engineering educators willing to advertise himself as such. He has been instrumental in introducing tools and techniques from the study of teaching and learning into engineering education. With Stice and Woods has has authored a widely acknowledged series of papers on the future of engineering education titled *The Future of Engineering Education*. [105, 106, 107, 108, 109, 110] He is a chemical engineer.

James Stice has worked with Felder on a number of engineering education initiatives. He is a chemical engineer.

Clive Dym is a leading researcher into the teaching of engineering design. He is the director of the Center for Design Education at Harvey Mudd University. In addition to a number of papers on the teaching of design and a number of excellent design texts, he

[11] It is interesting to note the number of chemical engineers who have made major contributions to engineering and engineering education. Prominent members of the systems community, such as Peter Checkland and Mike Jackson, are also chemical engineers.

has also organized a series of workshops on design topics. [92, 91] He is trained as an aeronautical engineer.

6.9.2 Engineers

The individuals listed below have all written about engineering as a discipline and a state of mind. Unfortunately, two have died (as indicated by the symbol †). Their works are sufficiently important that all participants in discussions of engineering and engineering education should be aware of their contributions.

Herbert Simon† was a nobel laureate in economics who devoted his life to understanding and enhancing human decision-making and problem-solving processes. His *The Sciences of the Artificial* is one of the most elegant discussions of the issues facing engineering. [220] He was multi-talented.

Christopher Alexander† was an architect who developed an innovative approach to design that has since become extremely popular in software engineering. His concept of a design pattern currently dominates object oriented design and is being expanded into areas such as organizational and engineering design. [1, 2, 3]

Norman Ball is a consultant and professor specializing in design, technology, and values. He has written a number of books describing the role of engineering in Canadian history. [11, 12, 13] He is a technical historian.

Donald Norman is one of the pioneers in human-centred design. His book *The Design of Everyday Things* supports the notion of engineers as mediators between the physical and the social. [186] He has also published numerous essays on the processes and attitudes of design. He was trained as an electrical engineer.

Henry Petroski is likely the best known living engineering author. His popular works trace the designs of many common engineering artefacts. [201, 199, 200] Petroski often contributes to journals such as ASEE Prism where he discusses broad trends and issues within the discipline of engineering. [203, for example] He is a civil engineer.

Eugene Ferguson is a historian who has written extensively on the history and evolution of engineering. *Engineering and the Mind's Eye*, his most recent work, discusses the role of perception and art in design. [111]

Samuel Florman is the only widely known engineering author to discuss the ethical and philosophical aspects of engineering. His books *The Civilized Engineer*, *The Introspective Engineer*, and *The Existential Engineer* are all unique contributions to the modern discussions of engineering. [115, 117, 116]Florman's vision of engineering is closest to that expressed in this thesis. He is a civil engineer.

Walter Vincenti is one of the few engineers who has a documented interest in the history and philosophy of engineering. His book *What Engineers Know and How They Know It* is one of the very few that discusses the nature of engineering knowledge and practice. [262] He is an aeronautical engineer.

Carl Mitcham is a philosopher who specializes in the social and philosophical aspects of technology. His investigations into the differences between science and engineering are distinct within the philosophy of technology community. He is also the editor of *Research in Philosophy and Technology*.

A facilitated progression through the stages of the SSM with as many of the aforementioned participants as possible would be a major boon to future discussions of engineering education. Ideally the result of the process would be one or more shared descriptions of engineering and engineering education that would be used to frame further investigations.

6.10 Industry has lost the right to direct engineering education

An article of faith among many engineering educators is that industrial relevance is a key criterion for quality engineering education. Discussions of the past (*The Other Re-engineering of Engineering Education* [219]), present (*Industry Expectations of New Engineers: A Survey to Assist Curriculum Designers* [165]), and future (*Evolution of Engineering Education in Canada* [29]) of engineering education all devote significant efforts to defining and incorporating the needs of industry into engineering education. However, an evaluation of the relationships between engineering education and industry reveals that this belief must be challenged.

All of the documents mentioned here and in chapter 4 state that engineering education must meet the needs of industry. However none of them define the term 'industry'. Simply understanding how the various engineering education stakeholders use the term would represent a significant step forward in resolving some of these issues.

There is likely no better example of how industry and engineering education interact than cooperative education. As the amount of theory comprising an engineering education increased, it became more difficult to include the practical, hands-on material deemed relevant to industry into the eight months of classroom study. The straightforward solution was to shift this material into the four months spent outside of the classroom. Students would spend this time working in and for industry. Even before it became the University of Waterloo (UW), the Waterloo College Associate Faculties chose to adopt this model of engineering education[12]. [270] The years since 1957 provide a glimpse of how the University of Waterloo vision of the cooperative relationship has been altered by the actions of industry.

As described in an early promotional brochure the cooperative approach envisioned by UW was one where responsibilities were shared between university and industry. [270] The university was to provide solely theoretical training while industry was to provide

[12] While Waterloo College was among the first to adopt the cooperative model, at present all Canadian engineering schools, save Lakehead, offer cooperative education programmes. Of the 34 Canadian schools, 14 have one or more departments that require their students to participate in cooperative education. [36]

organized, practical training[13]. This vision is admittedly idealized and some blurring of the boundaries was to be expected. The actual results have been that industry, speaking broadly, has almost completely shirked its responsibilities. The universities are expected to provide both theoretical and practical skills while industry deigns to provide employment and a salary[14]. While this description is also both polarized and generalized it has been influenced by both personal experiences and the experiences of peers.

At present, industry controls the cooperative relationship between itself and UW through its hiring. From personal discussions with the Dean of Engineering at UW, a drop in placement rates of 2% is sufficient to prompt serious discussions within the faculty. The faculty will even consider changes to curriculum content to increase marketability. From personal and peer experience, companies that offer cooperative placements seek particular skills and techniques. They rarely express a desire for theoretical skills, preferring practical experience. The UW engineering administration appears to feel that it has no choice but to ensure that the UW engineering curriculum provides as much of this practical experience as possible. The most obvious manifestations of this arrangement can be seen in the choice of introductory computer programming languages. The languages appear to have been chosen with little or no regard to their ability to support learning. Languages are chosen that meet industry needs, regardless of the conceptual difficulties they may cause students. Industry is able to use cooperative education to procure a steady stream of trained workers without having to make any significant investments.

Corporate training further demonstrates industry's lack of commitment to meaningful education. From personal experience as an instructor teaching software design and development, companies such as Nortel are not willing to invest in real learning opportunities. The preferred course lasts two or three full days, has no post-course follow-up, and has no on-the-job training. Students are expected to become sufficiently proficient in a new skill that they can immediately apply it to their work. When asked why they are taking a course, most students answer that their manager requires that they be able to work with the particular technology immediately. This teaching environment is not conducive

[13] This vision of complete separation may seem naïve but is was presented in this form in [270].

[14] In some cases they may also provide formal training. My experience, having been through six cooperative work terms at companies ranging in size from IBM to a 10-person start-up, is that most companies assume that their cooperative students will learn "on the job" and do not provide such opportunities.

to effective learning. When these students return for other courses it is clear that not only have they have forgotten many details but, more importantly, they were not able to effect the changes in cognition that meaningful learning should have engendered.

A key phase of the relationship between industry and engineering education takes place after graduation. University students, even those who go through a cooperative programme, generally apply to entry-level industry positions. There is a number of concerns associated with this phase of the relationship. The two that are most relevant to this discussion are the correspondence between the hiring criteria and the educational agenda of industry and the hiring practices themselves.

In the United States companies are able to procure a limited number of "H-1B" visas for employees with skills that are either unavailable or insufficiently available in the American graduate pool. In recent years, the high technology industry, and in particular the software sector, has lobbied for an increase in the number of such visas citing inadequacies in both the American system of education and its graduates. Starting in 1998, formal research was undertaken to determine the veracity of these claims. In a report titled *Debunking the Myth of a Desperate Software Labor Shortage*, Dr. Norman Matloff presents a reasoned, rigorous, and researched counter to the claims of industry. [174] A number of the companies that Matloff singled out for making particularly unfounded claims are also vocal proponents of change to technical education. [174, 243, 223, for example]

Formal research into the correspondence between the skills industry claims to desire and the skills it seeks when hiring might have equally interesting results. There are numerous calls for the development of particular skills in technical education. [243, 223, for example] These calls tend to focus on skills and attributes such as:

- Communication
- Information management
- Problem solving
- Adaptability
- Responsibility
- Positive attitudes
- Teamwork
- Project management
- Manufacturing skills
- Integration

These skills are strikingly similar to those mentioned in the engineering accreditation criteria and in the recommendations for the future of engineering education (see chapters 3 and 4). However, these may not be the skills that would assure an applicant of an entry-level technical position. Personal experience leads me to believe that these skills, and broad technical knowledge, are secondary considerations. Hiring appears to be done on the basis of particular technical keywords. The existence, and use by large companies such as Nortel, of software to filter resumés based solely on keywords supports this belief. In short while the CEOs may cry out for particular skills there is little evidence that their cries are affecting the hiring criteria at entry-level positions.

These same CEOs continue to treat technical graduates as peons in their organizations. A recent press release titled *Hi-tech CEOs Say Value of Liberal Arts is Increasing* was cited across Canada and continues to feature prominently on the web pages of a number of faculties of arts and science.

> "We have an equally strong need for those with a broader background who can work in tandem with technical specialists, helping create and manage the corporate environment.
>
> A liberal arts and science education nurtures skills and talents increasingly valued by modern corporations. Our companies function in a state of constant flux. To prosper we need creative thinkers at all levels of the enterprise who are comfortable dealing with decisions in the bigger context. They must be able to communicate – to reason, create, write and speak – for shared purposes: For hiring, training, managing, marketing, and policy-making. In short, they provide leadership." [181]

This press release, which was endorsed by the CEOs of such companies as Sun Microsystems of Canada, Sprint Canada, IBM Canada, and BCE Inc., presents technical employees in an extremely negative light[15]. Engineers must be counted among this group. The vision expressed in this release is inimical with the vision of engineers as mediators between the social and the biophysical worlds.

Interestingly, there appear to have been no curriculum suggestions made by the CEOs with respect to the liberal arts. Where they are willing to prescribe particular skills, technologies, and techniques to technical faculties they seem willing to allow the liberal

[15] This press release was published at a time when provincial funding for liberal arts programmes was in jeopardy. Accordingly the view expressed by the release may be biased.

arts to proceed undisturbed. This position makes little sense given that a number of the skills being requested of engineers, such as improved communication, appear also within the liberal arts experience. Why the CEOs are unwilling to make suggestions to the liberal arts community similar to those it makes to the engineering community is not known. Regardless, it is clear that these CEOs, and by extension the industries they represent, must be kept from controlling the evolution of engineering education.

Beyond all of the reasons given thus far for curtailing the influence of industry on the direction of engineering education there is one simple pragmatic concern. From discussions with administrators at the University of Waterloo it takes approximately three years to develop and implement a new engineering curriculum. Once that curriculum is in place there is an additional four or five year delay until the first graduates of the programme enter industry. In total there are between seven and eight years separating the beginning of a new initiative in engineering education and the first products of this initiative. If industry and media pundits are to be believed technology is progressing sufficiently rapidly that after this length of time most detailed knowledge will be obsolete. Industry, through their hiring practices and their pressures on engineering educators to incorporate contemporary tools and techniques, has demonstrated itself incapable of planning over this long a horizon.

By shirking their responsibilities to cooperative education and to the training of their own employees, as well as by adopting entry-level hiring practices that may value tactical over strategic technical skills, industry has shown itself unwilling to participate actively in engineering education. Given the predominantly short term focus taken by industry and the delays inherent in designing and implementing a curriculum, industry must not be allowed to drive engineering education. Their input is valuable and should be incorporated but they must not be given an equal, let alone a dominant, voice in present and future discussions.

6.11 Engineers have lost the right to direct engineering education

The discussion in section 6.10 concludes that industry must not be permitted to direct engineering education. Through the provincial regulatory bodies, government has already declared itself incapable of regulating, and by extension guiding, engineering. The task of directing engineering would seem to fall to the engineering profession and its constituent engineers. It is unfortunate that this constituency has already demonstrated itself incapable of directing engineering education. Further it has demonstrated no initiatives that would imply that it will ever become so capable.

The engineering profession, as represented by its provincial and national organizations, has in large part absolved itself of responsibility for directing and monitoring engineering education. These responsibilities have been passed on to engineering educators. At present the profession is only able to influence engineering education through the critical reports discussed in chapter 4. [29, 28] The complete lack of documentation detailing any follow-up activities related to these reports, coupled with the consistency of their messages over time, leads to the conclusion that the effects of these reports has been minimal.

The CCPE is titularly responsible for accrediting engineering programs across Canada. In large part it has delegated this activity to engineering educators. Of the 15 current CEAB members, 9 are, or were, members of an engineering faculty. While the CEAB Accreditation criteria state "In the selection of members for the CEAB, consideration should be given to maintaining good balance between academic and non-academic representatives and to maintaining representation from various disciplines." [32] in practice it appears that engineering educators make up the majority of the membership. Regardless of their background, all of the members of the CEAB have been indoctrinated with the views and beliefs of the group. According to the criteria the only requirement for membership of the board is registration as a professional engineer. Based on personal discussions it appears that there are significant unspoken criteria. Foremost among these criteria is the expectation that the individual must have been a team leader during multiple accreditation visits. Becoming a team leader requires participating as a team member during multiple visits. By the time they are eligible for CEAB membership an individual has been duly indoctrinated. In turn the engineering educators who make up the CEAB have in many cases allowed their host universities to dictate the structure and assessment techniques used in their courses. Finally, the universities have begun to allow the courts to dictate the degree of discretion professors are allowed to exercise when assessing students. [151, 88, 47, for example] This situation is depicted in figure 6.2. From discussions with administrators at

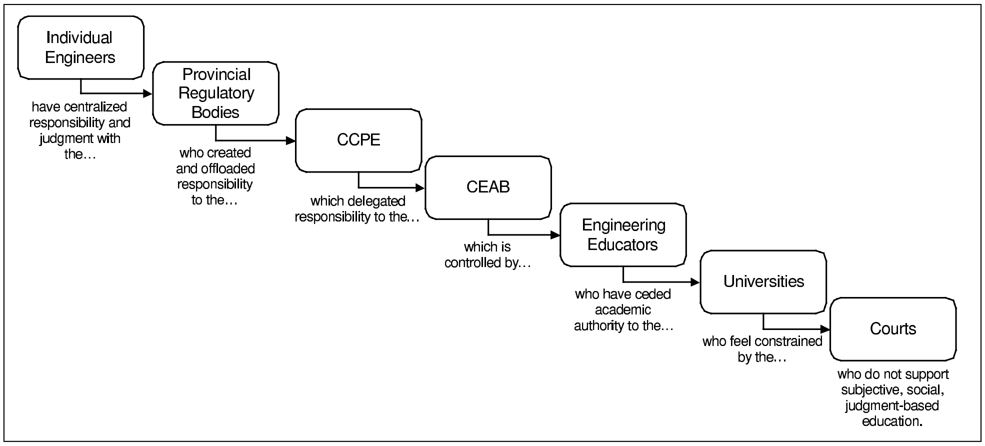

Figure 6.2: The passing of responsibility within engineering

the University of Waterloo this situation does not exist in other countries. For example in France engineering professors are able to exercise their professional judgement and promote or hold back students regardless of the marks they have received.

This informal indoctrination undergone by CEAB members represents the key difference between the Canadian and American systems of accreditation. At the criterion level the differences between the two countries are minor. Owing to the need to maintain mutual recognition both groups monitor the criteria and activities of their counterparts.

> "Our close cooperation with the U.S. Accreditation Board for Engineering and Technology (ABET) has made it possible for CEAB to monitor the implementation of output measures in ABETs new EC2000 accreditation system. CEAB has observed several accreditation visits that were conducted using the EC2000 system. Although we agree with the concept of using output measures, we believe that more time is needed for the full development of the EC2000 system and to assess the long-term effects of this significant change. CEAB has adopted a number of output measures in our own accreditation process, including the evaluation of capstone design projects, transcripts and examinations, and the inclusion of self-evaluations in the documentation provided by universities prior to an accreditation visit." [30]

What neither organization appears willing to admit is that accreditation in general, and the fundamental difference between the ABET and the CEAB in specific, is a social process. According to senior engineering administrators at the University of Waterloo, the calculation of CEAB Accreditation Units is in practice little more than an exercise in creative accounting. Their belief, influenced by personal experience, is that a department will be accredited if it can convince the visiting team that it deserves accreditation. The fundamental difference between ABET and the CEAB is the process of indoctrination that a visiting team member must undergo. According to PEO employees who interact with it, the CEAB has adopted an unwritten yet apparently inviolable system where one must "work through the ranks" before being admitted to the Board. ABET is described by these individuals as being much more lax in choosing team and board members. Unfortunately ABET does not document their membership requirements. Any concerns on the part of Canadian engineers or engineering educators regarding the rigour of ABET accreditation appear to be based solely on the indoctrination of the ABET membership. The fact that neither organization is willing to address this interpretation of accreditation, coupled with the lack of documentation detailing their respective indoctrination process, detracts from their moral authority to direct engineering education.

Taken alone the delegation of responsibility for directing engineering education to indoctrinated engineering educators is excusable, if somewhat incestuous. What cannot be excused is the professional misconduct being perpetrated by the vast majority of Canadian engineering educators while performing their teaching duties.

In Canada professional engineers are expected both to control engineering curricula and to teach courses that focus on engineering science and design. These two types of courses must make up one half of an undergraduate engineering curriculum. [32]

> **2.3.5** Faculty teaching courses which are primarily engineering science and engineering design are expected to be registered professional engineers in Canada.
>
> **2.3.7** Responsibility for initiating changes in the curriculum of the engineering program may be placed in [an appropriate body]. It is expected that a majority of the members of such a body be registered professional engineers

in Canada.

The accreditation criteria themselves are also controlled by professional engineers.

1.5.1 All members of the CEAB must be registered professional engineers in Canada.

Professional engineers control the criteria, implement the curricula that meet the criteria, and deliver significant portions of the curricula. Therefore these activities are professional engineering activities that must adhere to the CCPE code of ethics. [35] This code of ethics includes the following precepts:

2 offer services, advise on or undertake engineering assignments only in areas of their competence and practise in a careful and diligent manner;

4 keep themselves informed in order to maintain their competence, strive to advance the body of knowledge within which they practise and provide opportunities for the professional development of their subordinates;

There is a large body of evidence that suggests that many engineering educators are violating their code of ethics with respect to their engineering education activities. This body of evidence consists primarily of research and position papers that describe the need to instruct engineering educators in engineering education. [265, 267, 126, for example] The TRACE office at UW does not break down the attendance at its instructional seminars and workshops by faculty. However based on personal experience and communications the number of engineering faculty members in attendance is less than expected given their numbers across campus. While it is possible that faculty members are engaging in private study there is little evidence to suggest that this is generally the case.

One could make a case that formal study into engineering education does not make for superior engineering education. This argument is similar to that discussed in chapter 4 with respect to the qualifications of the authors of the critical reports. All professional engineering educators have experienced engineering education. Their experiences should be considered adequate preparation to train other engineers. While there is some merit to this argument the profession itself considers it inadequate. The reports from chapter 4 all discuss the importance of improving the teaching skills of engineering educators. The broad notion of scientific engineering also dismisses this argument. One could just as easily state that an engineer with sufficient experience does not need theoretical training. The profession has rejected this approach to engineering in the disciplines. It is high time it applies the same standards to engineering education.

The notion of professional training and designation in engineering education has already been established in Europe by SEFI (see section A.1.1). There is no reason why this approach could not be taken in North America. Thus far there has been no documented discussion regarding so doing.

Critics of this approach to engineering education may argue that higher standards are redundant because the system is currently working. This argument is flawed for two reasons. First, there have been no documented, researched, rigorous attempts to demonstrate that the system is in fact working. At this point there has been insufficient discussion to even begin to decide what 'working' means with respect to engineering education. Second, the discipline of engineering is predicated on the notion of continual change. Especially when dealing with social systems the constraints and criteria that inform the system are in constant flux. To declare that engineering education is working and as such should not be changed is to deny this fundamental aspect of engineering.

At present engineering education is intended to serve the needs of the engineering profession. [32]

1.1.1 Engineering programs offered by Canadian universities will meet or exceed minimum educational standards acceptable for professional engineering registration in Canada.

The CEAB accreditation criteria exist to ensure that engineering graduates are qualified to join the engineering profession. A question that has not been pursued thus far is whether those who desire an engineering education share this goal. Detailed figures on the number of engineering graduates who register with the profession or who go on to work in engineering fields are not available. Anecdotal evidence suggests that the trend, both over time and with respect to the maturity of the engineering discipline, is downwards. While the engineering profession may believe that the goal of the engineering education system is to produce professional engineers, graduates of these programmes may not agree. [39] The question being raised is which constituencies should the engineering education system serve, and how should it do so?

As alluded to in section 6.10, engineering educators, and by extension the engineering profession, have allowed industry to dictate a number of aspects of engineering education. In doing so the engineering profession may have failed in their duties to the public. As a self-regulating profession, engineers are expected to answer to, and serve the needs of, society[16]. The engineering profession is in the awkward position of having to decide how best to accomplish these goals. It can be argued that by tailoring their programmes to meet the needs of industry, engineering educators are in fact serving the public. An engineering graduate who is not hired cannot oversee the activities of industry from within. The counterpoint, as has been described previously, is that an engineer who is suited for industry may not be as well suited to serve the public. Neither the engineering journals nor the engineering profession appear to have published the records of any discussions of these issues. The closest most engineers appear to come to examining these issues is under the umbrella of engineering ethics. [5, for example]

Engineers have had significant opportunities to direct engineering education. It is unfortunate that their accreditation activities, critical reviews, and strategic plans appear to have had little effect, that they do not hold the educational activities of engineering educators to the same standards as other professional activities, that they have not considered the evolving goals of the students, and that they have allowed industry to dictate some of their direction. Until they begin to address these issues, the engineering profession has little right to continue to direct the course of engineering education[17].

[16] Admittedly in many cases they answer primarily to themselves.

[17] There has been some cause for hope that engineering educators would move beyond criticism to creation and innovation. For example in 1969 a paper titled *A New Plan for Engineering Education* was published. [130]. 1996 saw the publication of a similarly visionary paper, *Engineering Education – The Way Ahead*. [140] Unfortunately the engineering education system as a whole has resisted the changes called for in these papers.

6.12 An embryonic, complex systems vision of engineering

> "God grant us the serenity to accept the things we cannot change, courage to change the things we can, and wisdom to know the difference." – Anon.

> "God grant us the serenity to accept the things we cannot change, courage to change the things we can, and sufficient bloody-mindedness not to distinguish between the two." – Jason Foster.

Engineering is currently a directionless 'mess'. Industry and engineers have been limiting its evolution by valuing short term training goals over education, and by valuing teaching less than other professional activities. If engineering is to reach its full potential, a new vision is required.

An enabling vision for engineering education cannot be found in the existing literature. Florman is the only engineering author of note who focuses on these issues. [116, 115, 116] Unfortunately, his discussions focus on ethics and personal opinion without recourse to study or dialogue. The writings of Simon, Petroski, Vincenti, and Ferguson all touch on these issues but do not acknowledge them as a formal topic of discussion. [220, 201, 199, 262, 111] The philosophy of science community has only recently acknowledged that engineering may have a distinct philosophical position. [133, 215] This realization has not yet resulted in an organized research programme.

In order to address the lack of an enabling vision for engineering, this section presents the author's vision for the future of engineering. Given the messy, unframed nature of engineering, the vision presented in this section is necessarily biased and incomplete. This vision builds on the discussions presented in this chapter and in those that preceded it. It emphasizes issues of philosophy, metaphysics, ethics, and beliefs over skills and knowledge.

In broad terms, this vision has two components. The first is a framing of engineering using the model set out in section 6.6. The second is discussion of the relationships between engineering and design, systems, and complexity. This discussion implicitly provides an updated and expanded version of the original vision of Systems Design Engineering.

6.12.1 Engineering as discipline

Section 6.6 introduced the notion of a discipline as a social entity. It also proposed a model that describes the necessary components of a discipline. Whatever else engineering may be, it is first and foremost a discipline. Therefore, it can be described in terms of the four components of this model: languages, texts, themes and connections. This description takes as a given that the student engineer has experienced higher education as described in section 6.5 and is beginning the professional education described in section 6.7.

6.12.1.1 The languages of engineering

The languages of engineering are:

- The languages required for general higher education, including semiotics, modelling, rhetoric, etc.
- Mathematics[18]
- Information
- Algorithms

The concepts of information and algorithm are not currently considered core languages of engineering. Both need to be added to the engineering lexicon. The language of information, through texts such as entropy and exergy, is the only one to explicitly take into account different perspectives. Some texts, such as thermodynamics and relativity, also incorporate the notion of an observer. However, these texts are based on calculus, algebra, and ergodic statistics, and therefore use their languages in a manner substantially different from their original intents. Given the prevalence of computing in modern engineering, engineers must be able to speak using the language of the algorithm.

[18] It it important that engineers be exposed to more mathematics than the triumvirate of calculus, algebra, and ergodic probability. For example engineers should be exposed to Bayesian probability. When designing a new entity or intervention in many cases it is not possible to repeat the experiment. Repetition is the core of ergodic probability. In contrast Bayesian probability is predicated on the approach of developing an initial probability assessment and then updating this assessment based on new information.

6.12.1.2 The texts of engineering

There are innumerable texts that make up engineering. Particular collections of texts have given rise to the various engineering disciplines. Not all of the texts of engineering are expressed solely in the languages of engineering. Some are expressed as stories or anecdotes. As described in *The Social Life of Information*, communities of designers and problem solvers tend to express their tacit knowledge using stories and sagas. [21]

The texts of engineering are particular models, approaches, and higher-level languages. Examples of the texts that are currently part of engineering include:

- Thermodynamics
- Statics
- Dynamics
- Chemistry
- Fluid mechanics
- Electromagnetism and Optics
- Systems

It is impossible to create a complete or current list of the texts of engineering. New texts are constantly being created and older texts retired from active use or transferred to other disciplines.

6.12.1.3 The themes of engineering

Themes form the core of engineering. While the languages facilitate communication and the texts facilitate practice, the themes facilitate the development of meaning. Unfortunately, there are very few direct discussions of the themes of engineering. The direct discussions generally deal solely with engineering ethics. The research cited in this thesis suggested a number of themes.

Engineering is about simultaneously constructing and destructing limits. A key activity within engineering is the construction of limits. For example, engineers decide on road speed limits, based on surface, inclination, and trajectory. Other limits set by engineers include permissible heights of buildings, maximum RPMs in a motor, and the maximum clock frequency of a microchip. Engineers set these limits to control risk and to promote particular outcomes, such as a stable structure or repeatable computations. At the same time, the engineering community is constantly trying to remove or surpass limits.

Buildings get taller, bridges get longer, and microchips and engines get faster. Engineering is in dynamic tension between limiting what can be done and overcoming these limitations.

Engineering is about taking responsibility without complete understanding. A core component of being a differentiated member of a society is the taking of responsibility. Society expects individuals with more training and expertise to accept greater responsibility for their actions. This is true of both individuals trained in first aid or the martial arts and registered professionals.

Rules and codes are a means to shift responsibility from the individual to the larger group. Rules and codes can only exist when their contents and their contexts are sufficiently well understood that risk and surprise are minimal. So long as the rules are followed the follower is absolved of personal responsibility.

Engineers are required when the context or the content cannot be understood sufficiently to form codes or rules. There are situations and circumstances where neither theory nor practice can provide guidance. It is within there situations that engineers and engineering exist. An engineer will never have sufficient information and understanding to decide with certainty what design to use or approach to follow in a particular circumstance. Instead the engineer must use experience, intuition, and perhaps nothing more than faith, to decide on a course of action with the knowledge that they, and only they, are responsible for the outcome.

Engineering is about making and breaking precedents. Precedents are an accepted mechanism for coping with ambiguity. A precedent is less strict than a code or rule and, in theory, supports further interpretation. In practice, precedents tend to quickly degenerate into dogma. Once a precedent has been set, it can be used to justify repeating a behaviour or decision. Setting precedents is one of the activities of engineering. The first engineer who develops, and takes responsibility for, a new design or approach is in effect creating a precedent. Should their design be adopted by others it becomes a best practice. Certain best practices then become codified. Approaching a new situation and developing a novel approach, in the almost certain knowledge that it will set a precedent, is an extremely stressful activity. Equally stressful is deciding that an existing precedent must be ignored or substantially modified. In order for an engineer to adapt to novel and uncertain circumstances, that individual will, at times, have to ignore precedent.

Engineering is the interface between *how* and *why*. The engineer has to strike a balance between the experiential and the theoretical. Theory attempts to explain the *why* of a phenomena while experience, often structured as precedent, demonstrates the *how*. Theory and experience are linked and it is the engineer who most strongly embodies this link. One of my calculus professors related an anecdote that demonstrates this theme. Engineers allegedly "discovered" operator theory, in which differentiation and integration could be treated as multiplication and division. They had no theoretical basis for their discovery and treated it as a useful, yet suspect tool. Applied mathematicians toiled for years before discovering that it was an implicit application of the Laplace transform. Upon being so informed the engineers incorporated this explanation into their teaching and accorded the theory more trust. Speaking stereotypically, where mathematicians were unable to discover practical applications for the Laplace transform and technicians simply applied operator theory, engineers were able to marry these two perspectives and create a theoretically rigorous yet simultaneously practical tool.

Engineering is about making itself obsolete. All engineers work towards the goal of rendering their profession obsolete. That they will never attain this goal is an unimportant consideration. From the point of view of risk and responsibility an ideal world is one where there is a preferred, safe, and predictable approach for every situation. This is the world of codes and rules. Over time the number of rules and codes will grow in spite of occasionally suffering retractions. As they grow, fewer engineers are required to deal with the exceptional and the unforeseen. Taken to the extreme, there will eventually be no need for engineers, only for technicians. This vision is probably unattainable (see section 6.12.7). Nevertheless, it is one of the defining goals of the engineering profession.

Engineering is about scepticism. In order to accomplish the destruction of limits and the breaking of precedents, the engineer must approach his or her activities with scepticism. The scepticism called for in engineering is the bounding of trust. Ferguson provides an example of when the trust in a tool was not bounded. [111] A civil engineer used a software tool to assist in the design of a complex set of trusses. The tool assumed a particular mode of beam failure. After the structure was built, it collapsed under a snow load that was within the design parameters. The forensic examination showed that the beams failed in a different mode. The engineer in question did not bound his trust of the tool and, as a result, was professionally negligent. In *Remaking the World* Petroski devotes the chapter titled "Failed Promises" to this topic. [202] Bounded trust requires that the engineer be aware of the constraints and assumptions that define and limit all of their tools. Formal theories, including fluid dynamics and the mechanics of deformable solids, have limitations no less severe that those embodied within software or based on experience. For this reason, the engineer must always temper theory with experience, and vice versa.

The themes of engineering are created both within and outside of the discipline. The public, and the subset thereof who enter into engineering, have also created an engineering mythology with recognizable themes. There have been fewer attempts to documents this external vision of engineers and engineering than there have been to document the internal vision. [281]. As with the insider perspective, the outsider perspective on engineering must in many cases be inferred.

Perhaps the most interesting demonstrations of the public perception of engineers, and by extension of engineering, can be found in the entertainment industry. While there are few examples of engineers as main characters, Scott Adams' Dilbert is the notable exception, engineers have played a number of supporting roles. There are similarly few examples of movies where engineering plays a central role. Engineering has become a topic of interest in television programmes that document the construction, the destruction, or the catastrophic failure of large civil engineering projects.

A selection of popular culture references to engineering and engineers includes:

- Montgomery Scott[19]
- Geordi LaForge[20]
- B'Elanna Torres[21]
- The Doctor[22]
- Dilbert[23]

[19] Chief Engineer of the USS Enterprise from the original *Star Trek* television series.
[20] Chief Engineer of the USS Enterprise from the *Star Trek–The Next Generation* television series.
[21] Chief Engineer of the USS Voyager from the *Star Trek–Voyager* television series.
[22] Time-travelling adventurer from the *Dr. Who* television series.
[23] Cartoon character with a degree in Electrical Engineering from MIT.

- Red Green[24]
- Angus MacGuyver[25]
- *Scrapheap Challenge/Junkyard Wars*[26]
- *Extreme Machines*[27]
- *Hyperion Bay*[28]
- *October Sky*[29]
- *No Highway in the Sky*[30]
- *Apollo 13*[31]
- *PMK (Popular Mechanics for Kids)*[32]
- *Beyond 2000*[33]
- *Building Big*[34]
- *L.A. Engineer*[35]

Each of these examples incorporates a different amount of engineering content. Montgomery Scott is first, foremost, and only an engineer. In contrast, while the main character of *Hyperion Bay* worked as a software engineer the episodes virtually ignored his profession. Whether the main characters of *MacGuyver* and *Red Green* are engineers is a question that remains unaddressed[36]. The status of the examples that focus on technology, including *Beyond 2000* and *Extreme Machines*, is also confusing. Leaving the resolution of these issues to future research, the examples imply the following set of themes:

- Engineers can develop technological solutions to virtually any problem (from almost every episode of Star Trek)
- Engineers are wildly creative (*MacGuyver*; *Apollo 13*; *Scrapheap Challenge*)

[24]Handy-man from *The Red Green Show* television series.

[25]Adventurer and occasional government special operative from the television program *MacGuyver*.

[26]Television program in which teams construct a device from scrap parts.

[27]Television program describing contemporary and prototype machine designs.

[28]Soap opera where the main character ran a high-tech start-up.

[29]Motion picture describing the attempts of two boys to build a rocket.

[30]Motion picture describing the efforts of an engineer to ground a potentially dangerous aircraft design.

[31]Motion picture describing the events at NASA surrounding the 13^{th} Apollo mission.

[32]Television program oriented towards pre-teen children that introduces them to the devices, both large and small, that affect their lives.

[33]Magazine-style television program that introduces its viewers to modern technologies.

[34]Television miniseries that discusses the architecture and engineering of large construction projects.

[35]Allegedly proposed by the American Institute of Engineers and patterned after *L.A. Law*. It was never produced. [281]

[36]In my opinion MacGuyver was not. He was a gifted tinkerer, but he had neither the formal training in the languages nor the connection to the community required to be an engineer. Similar sentiments can be expressed regarding Red Green

- Engineers pad their schedules so as to appear to be miracle workers (from a conversation between Montgomery Scott and Geordi LaForge)
- Engineers take their responsibilities personally (Ed Harris' character reaction to the challenge in *Apollo 13*; Montgomery Scott after the ambush in *The Wrath of Khan*)
- Engineers play with and develop new and innovative technologies (*PMK*; *Beyond 2000*)
- Engineers value technology more that people (from Montgomery Scott's explanation of the bar fight in "The Trouble with Tribbles", Dilbert's life)
- Engineers build structures, some of which fall down or explode (from *Building Big*)
- Engineering is based on strange rituals and special artefacts (Ed Harris' character's new vests in *Apollo 13*; MacGuyver's knife; The Doctor's scarf and sonic screwdriver)
- Budding engineers play with Lego, Meccano, and duct tape[37]

There have been no studies of these images of engineering nor of their effects on the profession. However given that these images are being integrated into popular culture by the entertainment industry, it is conceivable that they drive many of the relationships between engineers and policy makers. The effects of these images are likely to be most pronounced when examining applicants to engineering programmes. It is likely that those students who apply to engineering feel some kinship with one or more of these characters. If this is the case then one of the goals of engineering education must be to replace or augment these images with those that define this new vision of engineering.

6.12.1.4 The connectivity of engineering

Interactions between engineers are facilitated by a number of institutions and symbols. These facilitators include:

- Engineering Education
    - Engineering faculties (University of Waterloo)
    - Engineering mascots (Ridgid Tool)

[37] The potential negative consequences of Lego, relative to Meccano, on the creative abilities of budding engineers is discussed in [170].

    - Engineering programmes (Department of Systems Design Engineering)
- Shared Symbols
    - The Iron Ring
- Engineering Profession
    - Provincial regulatory bodies (Professional Engineers Ontario)
    - Provincial publications (*Engineering Dimensions*)
    - Engineering NGOs (Canadian Council of Professional Engineers, Canadian Academy of Engineering)
- Engineering Disciplines
    - Discipline-specific associations
    - Discipline-specific journals

These facilitators can be grouped into four categories. The first category relates to the education of the engineer. By virtue of being universal this category is most important. The second category relates to the shared symbol of the Iron Ring. From personal experience almost all Canadian engineering graduates choose to adopt this symbol. The third category relates to the engineering profession. Given that approximately 60% of engineering graduates enter the profession, and that this percentage is dropping, the importance of this category is much less than the first two. [39] The final category of facilitators, those which are specific to a single engineering discipline, is similarly less important.

The connectivity of engineering is interesting in that after graduation it depends primarily upon the individual and his or her colleagues. On university campuses, engineers have a strong presence and sense of community. After graduation, engineers appear not to maintain these relationships to the same degree as other professions.

6.12.2 The epistemology, ontology, and philosophy of engineering

There are many introductory texts that introduce new engineering students to their discipline. Such texts include *Engineering: an introduction to a creative profession*, *Canadian*

Professional Engineering Practice and Ethics and multiple *Introduction to the engineering profession* and *Foundations of Engineering*. [195, 17, 5, 158, 141, 226, 23] These texts exhibit a remarkable degree of homogeneity in both their structures and their content. A disconcerting omission in all of the texts is any formal discussion of the beliefs that underlie the discipline of engineering. The only similar topic that is common to many of the texts is engineering ethics. Unfortunately, the discussions of engineering ethics focus on the professional aspects of engineering, not on engineering as a discipline.

To date a single conference on the topic of engineering epistemology has been held. Unfortunately, while a high-level report on the proceedings is available there is no record of the event itself. [215] Given that the full title of the conference was *Epistemology and Ethics in Engineering* it is likely that discussions of engineering ethics dominated discussion.

In 2000, Hendricks, Jakobsen, and Pedersen published a paper titled *Identification of Matrices in Science and Engineering* in the *Journal for General Philosophy of Science*. [133] This appears to be the only paper that explicitly attempts to define the epistemological, ontological, and metaphysical positions of engineering. Beyond this unique contribution the paper is also worthy of note because of its unwitting mention of the techniques of graph theoretic modelling used in the Department of Systems Design Engineering (see section 5.1.3). [133, pp. 294–297] While the authors discuss these techniques and concepts they do not refer to them by this name, nor do they provide citations to substantiate their discussion. The substantive conclusions of *Identification of Matrices in Science and Engineering* are presented in table 6.2. Given the paucity of citations in [133], in addition to the paucity of research in this area, a number of these conclusions are debatable. The real value of table 6.2 is the way it organizes their comparison of science and engineering. A valuable exercise would be to analyse the works of significant engineering authors, such as Petroski and Florman, using this framing.

6.12.3 Engineering and its related fields

Almost every introductory textbook on engineering discusses the relationship between engineering and other related fields. Table 6.3 synthesizes the definitions presented in a number of introductory texts. [5, 141, 158, 17] The texts do note that these distinctions are approximations but their discussions of the nature and origins of the distinctions are

	Pure Science	**Applied Science**	**Engineering Science**
Examples	Hydrodynamics	Hydraulics	Theory of urban waste water systems
Delimitation of Objects	Idealized, isolated objects. Causal mechanisms		Physical (real) entities and artefacts in environments created by man. Intentionally determined.
Epistemic and Ontological Assumptions	Essential	Less essential	Adopted from pure science
Theory Structure	Hierarchical structure of nomological systems. Mainly mono-paradigmatic		Theory adopted to problems. Poly-paradigmatic. Ecclectical use of theory.
Methods	Derived from theory		Methods are more fundamental than theory
Values	Explicit justification. Truth is important		Implicit justification. Efficiency and practical usefulness. Pragmatic concept of truth
Exemplars	Building Research Competence		

Table 6.2: Preliminary conclusions [133, page 300]

minimal.

The new vision of engineering has to acknowledge that engineers are first and foremost concerned with the exception, not the rule. It is assumed that an individual qualified to be an engineer could acquire particular technical skills, in the form of the texts of engineering, as required. The training of this new engineer must therefore emphasize both the acquisition of new technical skills and the ability to function as the interface between theory and practice.

Field	Role and tasks
Scientist	Studies nature to advance human knowledge. Creates new knowledge.
Engineer	Applies science, mathematics, and economics to improve quality of life. Creates new things. Adapts theory to practice.
Technologist	Applies science and mathematics to well-defined problems.
Technician	Completes specific tasks under the direction of engineers and technologists.
Artisan/Skilled Worker	Uses manual skills to carry out the plan of others.

Table 6.3: Definitions of engineering and its related disciplines

6.12.4 Engineering and its disciplines

This vision of engineering dispenses with the notion of an engineering discipline as being central to engineering. Disciplines persist as administrative and public relations conveniences, not as essential aspects of engineering. The texts of engineering, collections of which define the different disciplines, change continually. For this reason, discipline-specific labels are detrimental from a public relations perspective. There is no guarantee that a graduate of an electrical engineering programme in the 1950s has the skills and knowledge expected of a contemporary graduate in that discipline. The converse is also true. A manager familiar with the electrical engineering of the 1950s is likely to find the skills of contemporary electrical engineers lacking. Given that an engineering career may span 40 or more years, any discipline-specific labels will cause more confusion than benefit.

One response to the perceived increase in the breadth of engineering knowledge has been to develop more and more specialized disciplines. This trend is especially popular in Europe and Asia[38]. In adopting this response, the engineering educators have allowed the short-term needs of industry to drive their evolution. Further balkanization of engineering

[38] Examples of specialized engineering departments, as opposed to designated options, include Thermal, Hydraulic, and Automotive Engineering [246] and Antennas & Radio Transmitters [207]

will move the discipline as a whole towards the current definition of a technician. Doing so ensures that engineers are incapable of fulfilling their social role. Engineers and engineering need to reclaim the leadership roles that were once theirs. This will not happen if they continue to choose a level of abstraction consistent with disciplinary specialization.

The notion of an engineering discipline also enters into discussions of professional regulation. Over the last 40 years the PEO has changed its position on this issue twice. The original professional designation was as an engineer with no reference to a particular discipline. At some point in the mid-1900s they switched to a discipline-specific designation. They have since reverted to the original designation. The PEO is currently discussing switching back to the discipline-specific designation in response to the proliferation of disciplines. From discussions with PEO staff members, there are no available records of the deliberations or reasoning behind any of the changes to the designations.

As described earlier, a discipline can be considered a particular set of texts defined at a particular point in time. A discipline has no relation to the languages and themes of engineering, and little relation to the connectivity between engineers. Given that engineers must be continually learning and adapting to varied and changing circumstances it is nonsensical to assign them a particular discipline. Unfortunately, contemporary engineering education focuses on the particular sets of texts. The programmes and the accreditation criteria all claim to ensure that the student engineer also receives training in general engineering. The degree to which this actually happens is not known. This approach to engineering education is short-sighted at best and professionally negligent at worst. Using the vision of engineering and engineering education presented thus far, based on the descriptions provided in the undergraduate calendar a contemporary engineer trained at the University of Waterloo as an "electrical engineer" is more properly described an an "electrical technician" with some limited exposure to engineering. [255]

6.12.5 Engineering and design

All engineering texts, whether targetted at engineers or at the general public, link engineering to design. [220, 201, 199, 262, 111, 195, 17, 5, 158, 141, 226, 23] In addition, there are numerous engineering texts devoted exclusively to this topic. [24, 263, 144, 93, 84, 95, 169] In general, all of the discussions focus on the "engineering design process". This process, which varies slightly among the texts, is always discussed as though it is a given. While the texts do allow designers to choose their own path through the process, the set of steps is invariant.

A defining insight of the founders of Systems Design Engineering was that design can be a topic of research and study. Almost all engineering programmes teach engineering design. Systems Design Engineering is one of the few that, originally, had as a mandate researching and promoting the use of multiple design processes and theories. There are many individual researchers, such as Dym and Warfield, who research design. [268, 92, 91] Systems Design Engineering was unique in treating design as a distinct topic. Unfortunately this research programme in design was one of the first to disappear. Current research into engineering design focuses on automation and computer assistance. [268, 91] This focus is consistent with the scientific and theoretical bent of contemporary engineering. While these are interesting issues, discussions of the philosophy that underlies design is more relevant to realizing the future of engineering. Such discussions are sorely lacking in the engineering literature.

6.12.6 Engineering and systems

A second defining insight of the founders of Systems Design Engineering was central role of systems concepts within engineering. When the department was founded the choice was made to pursue the branch of systems that focused on isomorphisms between physical systems. This limited application of systems concepts was sufficiently novel that it continues to distinguish the department. Students in Systems Design Engineering share stories of how their use of isomorphic tools during cooperative work terms amazes their colleagues. Unfortunately in the real world of engineering such modelling is handled by computer tools. From the standpoint of the practising engineer there is little need, beyond bounding their trust in their tools, to understand the isomorphic physical systems tools.

Since Systems Design Engineering was founded the systems community has branched out to encompass a myriad of different fields. This branching makes it difficult to define the systems field in any rigorous fashion. Jackson and Flood, two of the more prominent researchers in the systems field, have independently tried to span the systems disciplines. Jackson partitions the systems field into a number of categories:

- General System Theory
- Organizations as Systems
- Hard Systems Thinking
- Cybernetics
- System Dynamics
- Soft Systems Thinking
- Emancipatory Systems Thinking
- Critical Systems Thinking

For each category he provides a short annotated bibliography. [164] Flood, in *Rethinking the Fifth Discipline*, takes a different approach. [114] He identifies a number of prominent systems researchers and their approaches:

- Senge's *The Fifth Discipline*
- Bertalanffy's open systems theory
- Beer's organizational cybernetics
- Ackoff's interactive planning
- Checkland's soft systems approach
- Churchman's critical systemic thinking

Both Flood and Jackson research systems in the context of management. Accordingly their definitions of systems may be slightly biased. Most discussions of systems, whether found in journal papers, theses, dissertations, or books, define the systems concepts and present a brief (15–30 page) overview of a small subset of the field. [247, 131, 156, 122] At present there are no canonical, broad-based references that cover the systems field[39]. Developing such a reference is a future project that would greatly benefit the systems community.

Beyond being spread extremely thinly across a wide variety of areas, the contemporary systems community suffers from two major flaws. The first is that a significant portion of its membership promotes views that are neither popular nor accepted by the established scientific community. In and of itself a lack of acceptance is not necessarily a negative characteristic. The negative aspects arise when fellow members of the systems community also do not accept their views. Further, many of these views either do not have criteria with which to judge rigour or fail to meet established and accepted criteria. From personal

[39]Flood's *Rethinking the Fifth Discipline*, Flood and Carson's *Dealing with Complexity: An Introduction to the Theory and Application of Systems Science*, Weinberg's *An Introduction to General Systems Thinking*, and van Gigch's *Applied General Systems Theory* are all good starting points but none is oriented at the novice undergraduate student. [114, 113, 274, 259] Blauberg's *Systems Theory – Philosophical and Methodological Problems* may be the best book of all, but is not widely available and is predominantly a critique.[15]

experience at the 2000 conference of the International Society for the Systems Sciences (ISSS), the systems community is aware of this concern but is unable to rectify the situation.

The second, related flaw within the systems community is a lack of formal scholarship. This lack manifests in a number of ways including a lack of research funding, a dearth of experts in the fields, and a lack of respect among other academic disciplines. Again from personal experience at ISSS 2000, the senior systems practitioners are aware of these issues. During the president's speech he commented that members of the ISSS do not cite each others' works, nor do they cite any of the established literature. As the ISSS was scheduled to host a number of related groups at the 2001 conference, the president felt the need to admonish the membership to improve the quality of their scholarship. Of the major figures within the systems community only Checkland, in his paper *Systems and Scholarship: The Need to do Better*, has commented in writing on this issue. [44]

The systems theory of the 1960s was able to contribute significantly to the engineering of that era. The new, broader vision of systems can form the basis of the new vision of engineering. As it has expanded in scope from physical systems the systems field has been forced to address a number of issues including:

- How to frame messes
- How to set boundaries
- How to develop common cause among diverse stakeholders
- How to apply insights across perspectives and disciplines
- How to perceive and interact with both structures and processes

Some systems practitioners, such as Gharajedaghi and Banathy, have presented evidence that the systems concepts are evolving towards a new practice of design. [122, 16] The current and emerging attributes of systems mesh perfectly with the new vision of engineering. All future engineers should be trained as what might today be called systems design engineers.

6.12.7 Engineering and complexity

> "Forces that we cannot understand permeate our universe. We see the shadow of those forces when they are projected upon a screen available to our senses,

> but understand them we do not. Our universe is magical. All forms are arbitrary, transient and subject to magical changes. Science has led us to this interpretation as though it placed us on a track from which we cannot deviate." [137]

The final ingredient that makes up the new vision of engineering is the notion of complexity. As with systems, the term complexity is sufficiently broad and vague as to be effectively plastic. Further complicating the definition of complexity is its close affiliation with the fields of chaos and systems. Systems Design Engineering incorporated some limited aspects of complexity, in the form of stability theory, in its early curriculum and research areas[40].

There do not appear to be any canonical references or introductory materials that address in any complete fashion the broad topic of complexity. *Chaos* by Gleick and *Complexification* by Casti are two books that have attempted to introduce the concepts of chaos and complexity to a broad audience. [124, 37] Both books touch on a number of popular manifestations of chaos and complexity including the "Butterfly Effect", fractals, and strange attractors. *Complexification* includes more of the theoretical aspects of complexity such as Lyapunov exponents, formal systems, incompleteness, and algorithmic complexity.

As part of the efforts at MIT to develop the Engineering Systems Division, one of the founders of the division has put together an annotated bibliography on the topic of complexity. [228] While it is not suitable for publication, it does demonstrate the breadth of the field of complexity. Titled *Ideas on Complexity in Systems – Twenty Views* the paper ranges over topics including economics, risk analysis, business, organizational psychology, and transportation systems.

From the perspective of the new vision of engineering, complexity identifies a number of relevant issues including:

- Bifurcation, attractors, and catastrophes
- Irreducible uncertainty
- Emergence

[40] The stability theory courses within Systems Design Engineering focused on the application of the theory to the stability and failure of physical structures. These aspects and application of the theory have been widely incorporated into engineering. What is lacking, both within Systems Design Engineering and the engineering disciplines, is the application of the theory to other system types.

- Self-organization
- Feedback
- Coupling and cohesion

The field has yet to develop robust, practical techniques to address many of these issues. The one area where significant progress has been made is in stability (catastrophe) theory. While the basic techniques of stability theory have become part of mainstream engineering, in the form of the study of the stability and failure of structures, the more advanced aspects of the theory have not. Regardless of the maturity of the field's tools, engineers who are trying to cope with risk and uncertainty have much to benefit from a deep knowledge of complexity. Accordingly studies of complexity, along with studies of systems and design, must become the core of engineering education.

The links between engineering and complexity have already been acknowledged by one group within the field of complexity. Post-Normal Science (PNS) is one approach being advocated for dealing with complex situations. Silvio Funtowicz, one of the principal developers of PNS, has incorporated it into the governance work being undertaken by the European Commission. [121] As the expanded vision of engineering touches on governance and complexity, engineers must become aware of tools such as PNS. The PNS approach focuses on the social aspects of problem solving and decision making and as such complements the activities of systems thinkers such as Checkland. In *Science for the Post-Normal Age*, one of their earlier papers, Funtowicz and Ravetz distinguish between a number of scientific endeavours. [120] A summary of their categorizations is presented in table 6.4. Funtowicz and Ravetz consider engineering the be the interface between science and professional consultancy. While I respect that *Science for the Post-Normal Age* was written in 1993 and that it does not cite any resources on the philosophy of engineering[41], I feel that they have mis-categorized engineering. The engineer of today who is practising engineering belongs strictly within "professional consultancy". The engineer being described in this section belongs either at the boundary or completely within post-normal science.

A concern with linking engineering to complexity is that the perception of complexity as a useful tool may be on the decline. In the chapter titled "The End of Chaoplexity" in his book *The End of Science*, Horgan presents a scathing rebuke of the fields of chaos and complexity.

[41]This is understandable as there aren't any. Nevertheless this view of engineering is overly stereotyped.

Activity	Complexity	Motivation	Stakeholders and objectives	Source of guidance
Core science	Very low	Curiosity	Single stakeholder and objective	Technique
Applied science	Low	Mission-oriented	Single stakeholder and objective	Technique
Professional consultancy	Medium	Client-serving	Single stakeholder, multi-objective	Methodology
Post-normal science	High	Issue-driven	Multi-stakeholder, multi-objective	Philosophy

Table 6.4: Characteristics of the various types of scientific endeavour [131, Table 2.2]

> "So far, chaoplexologists have created some potent metaphors: the butterfly effect, fractals, artificial life, the edge of chaos, self-organized criticality. But they have not told us anything about the world that is both concrete and truly surprising, either in a negative or in a positive sense. They have slightly extended the boundaries of knowledge in certain areas, and they have more sharply delineated the boundaries of knowledge elsewhere." [143]

At the same time the National Science Foundation in the United States has created a division with a mandate to fund research into complexity, in particular as it relates to biological systems. [103] I believe that Horgan is correct in saying that at present the fields of chaos and complexity have not developed techniques to address issues of risk and uncertainty. Regardless of whether the fields can meet this challenge, complexity must become central to engineering. If the techniques cannot be developed, then by incorporating complexity engineering may lose some of the naïvity, and associated hubris, that has led to failures such as the BioSphere projects and the Aswan dam. If techniques to understand and address complexity can be developed then engineering, in its new role as mediator between the complexities of the social and the biophysical worlds, will be better able to fulfil its expanded purpose.

6.13 Andragogy and pedagogy will make the difference

Regardless of how it is framed, engineering education is fundamentally about teaching and learning. The accreditation criteria described in chapter 3, the critical reports discussed in chapter 4, and the experiences of Systems Design Engineering described in chapter 5 all acknowledge the need to improve the quality of teaching in engineering education. The effectiveness of improved teaching is further enhanced by improvements in learning. If the visions described in this chapter are to be realized then engineering education, engineering educators, and engineering students must all incorporate advances in andragogy and pedagogy.

6.13.1 Pedagogy

Pedagogy, interpreted as the art and science of educating children, is an established field of study. [166] While the term is somewhat amorphous, in general it refers to different tools and techniques used by teachers when interacting with students. Unfortunately the majority of the studies into pedagogy focus on primary and, to a lesser extent, secondary school instruction. That having been said there is still evidence that a knowledge of pedagogy can enhance undergraduate education.

Pedagogical studies have recently incorporated the study of different disciplines. This shift acknowledges that different students react to different material in different ways. Pedagogical techniques that work well for science may be different from those appropriate for history or english. While there are some pedagogical techniques with broad applicability, the hope is that targeted research can enhance teaching within particular disciplines. It appears that the vast majority of the discipline-specific research into pedagogy has focused on the teaching of science and mathematics to grade school children.

In 1993, Wankat and Oreovicz published *Teaching Engineering*. [265] This is the only resource of its kind available to engineering faculty members. Other books with similar titles, such as *Teaching Engineering: A Beginner's Guide*, are generally edited collections of journal articles. [126] These books do not have the same degree of cohesion and focus as that of Wankat and Oreovicz. *Teaching Engineering* covers many aspects of engineering education including assessment, lecturing, professionalism, and theories of cognitive development. The book is a good introduction to university teaching. Unfortunately it contains almost no discipline-specific content. From online discussions, it is apparent that there are no university-level resources that go beyond the basics of general pedagogy. There are many papers in the engineering education journals that do discuss the effectiveness of particular teaching approaches in engineering education. [123, 90, 196, 178, 129, for example] Such papers generally focus on single teaching techniques. The research approaches used by these researchers have been described by the editors of the journals within which they appeared as lacking in rigour. [94, 149] They do not represent a coherent effort to develop a discipline-specific pedagogy for engineering.

The systems community has invested almost no effort in documenting its approaches to teaching systems concepts or developing discipline-specific pedagogy. Three years of searching the literature yielded few journal references to the teaching of systems concepts. *The Teaching of Soft Systems Thinking*, published in 1991, retroactively applies one model of course design to an existing systems course. [278] *Bathtub Dynamics*, authored by an MIT systems dynamicist and a graduate of the Harvard Graduate School of Education, is an example of the kind of research that systems educators, and engineering educators, need to perform. [230] This article contains the preliminary results of a study of the effectiveness of graduate-level courses at MIT in imparting critical systems dynamics knowledge to students. Finally, while the systems dynamics community has been attempting to incorporate its ideas in grades K–12, it has published a single research paper describing how this might be accomplished. [87] There appear to be no papers of a similar nature that address the teaching of complexity.

6.13.2 Andragogy

The term 'andragogy' was coined in 1973 by Malcolm Knowles. [161] Andragogy, which was initially defined as "the art and science of helping adults learn", has since taken on a broader meaning. The term currently defines an alternative to pedagogy in that it focuses on the learner, not the teacher, regardless of the learner's age. The shift from teacher-centred to learner-centred education represents a major ongoing shift in education. This shift has emphasized the need for training in andragogy.

> "A bewildered student [in an Ontario grade school] told his teacher, 'We go to school so that you can teach us. Why should we teach ourselves when we have you?' ." [275].

From personal experience as a university teacher, this sentiment is shared by undergraduate students. Without formal training in andragogy, overcoming these difficulties will be an arduous, possibly unsuccessful endeavour.

6.13.3 Emerging adulthood

A new addition to the discussion of teaching and learning is the introduction of a new phase of social and physiological development[42]. Emerging adults share a number of characteristics:

- Age 18–29
- Significant changes to cognition and physiology
- Belief systems that are in flux
- Required to take personal responsibility for their actions
- Changes to their social roles
- Changes to their family structures
- Changes to personal commitments

Many undergraduate students are emerging adults. The environment of higher education, especially in the liberal arts, provides new experiences and structures that inform the changes that take place during this phase of development.

Research into the educational aspects of emerging adulthood has the potential to greatly benefit higher education, and the teaching of engineering, systems and complexity in particular. University graduates have been shown to retain the simplistic explanations that they were first exposed to in spite of later 'learning' more sophisticated explanations. [217] For example, many university graduates can not give a correct explanation for the seasons. [217] Given that one of the hallmarks of the emerging adult is changes in belief systems, research into facilitating these changes has the potential to improve education.

[42]The Society for Research on Adolescence has just created a Special Interest Group on Emerging Adulthood. The first meeting of the group will be in 2002.

Studies into emerging adulthood can also inform professional education. As described in section 6.7, professional education should in large part focus on commitment and responsibility. Facilitating the development of these attributes will be a part of the emerging adult research programme.

Regardless of how engineering education evolves it needs advances in pedagogy and andragogy if it is to succeed. It is important that engineering educators not succumb to the temptation to develop and adopt a single set of teaching and learning techniques. Individuals learn and teach differently. Engineering education will only succeed in incorporating the necessary concepts of systems and complexity if it makes developing the tools and techniques of teaching and learning its foremost priority.

6.13.4 The need for research into higher education

The need for an increasing number of engineers has been acknowledged by multiple levels of government across North America. At the same time higher education, especially in the technical disciplines, is under siege. The Council of Ontario Universities has released a number of reports that discuss current and future concerns with higher education in general. The reports include *Access to Excellence*, *How will I know if there is quality?*, *Will there be enough excellent profs?*, and *Ontario's Students, Ontario's Future*. [52, 221, 222, 51] When coupled with the engineering-specific reports such as *The Future of Engineering Education in Canada* the following picture of engineering education has been painted:

- There is an imminent loss of professors due to retirement.
- Demographic shifts will permanently increase the student population.
- Higher education participation rates are also increasing.
- The principle of universal access to higher education must persist.
- Faculty, especially in applied disciplines, are being attracted to industry.
- Graduate students and faculty members are succumbing to recruitment activities from abroad.
- Governments have placed the applied disciplines as the cornerstone of the new economy.
- The government and the broader public desire accountability of higher education.

- Government resources will never match those of industry.

The various levels of government have no choice but to react to this situation. Their potential reactions include:

- Allow class sizes to rise precipitously.
- Reduce quality and increase throughput.
- Replace professors with teaching assistants and sessionals.
- Restrict enrolment to university programmes.
- Hire professors from industry.
- Investigate and promote enhanced and alternative methods for teaching and learning.

Save for the last item these possible solutions are all unacceptable. They flounder due to insufficient resources, accountability, risk to accreditation, and social displeasure. Regardless of the approach the governments and universities take it is clear that research into teaching and learning will be pursued. Professors are currently not trained in the established techniques of teaching to large classes. Teaching assistants, sessionals, and industry teachers all require improved teaching skills to function effectively in the university setting. Research into teaching and learning is a valuable supplement to all possible solutions.

Enhancing teaching and learning in higher education has been part of the university agenda for a number of years. The Boyer report and its successors brought this issue to the fore. Many universities now include teaching, as well as research and service, in the evaluations for tenure and promotion. Some of these universities have created on-campus centres that focus on enhancing faculty skills in these areas. In North America there are two organizations that deal with the practical application of teaching and learning in higher education. Americans with an interest in faculty development turn to the Professional and Organizational Network in Higher Education (POD) while Canadians turn to the Society for Teaching and Learning in Higher Education (STLHE). Based on the electronic conversations that take place within these two organizations and on the topics covered at their respective conferences higher education continues to treat teaching and learning as supplementary activities.

One explanation for the lack of success of the teaching and learning centres is that they tend to focus their efforts on the humanities. This response is in keeping with the liberal arts focus of the Boyer report. As well, the applied disciplines have not been strongly encouraging their faculty to improve their teaching skills. This situation is ripe for change. The recent donation to Queen's university earmarked for the establishment of a chair in engineering education likely marks the beginning of a trend. NSERC has also entered the discussion through the incorporation of education into the mandates of its research chairs. While they, along with the CCPE and the other profession engineering organizations, have yet to commit funds explicitly to research into engineering education such a commitment will soon be a necessity.

Chapter 7

Conclusions

Engineering education is an undeveloped field of study. It has remained fundamentally unchanged for the past 50 years. The institutions in which engineering education takes place have remained relatively unchanged for an even longer period. In spite of this stability there is a paucity of historical records. Even today, in a climate known for accountability and measurements, there is no coherent picture of engineering education.

A synthesis of the documentation made available by engineering educators and the engineering profession cannot produce a comprehensive description of the current state of engineering education. Summary statistics and measurements associated with engineering education fail to exhibit any theoretical grounding. Save for these statistics and measurements there are only a few widely known and highly influential documents within the community of engineering educators. Of these documents, only the engineering accreditation criteria offer the potential for understanding the current state of engineering education. However, the descriptions they provide are neither comprehensive nor useful. The current state of engineering education is, at present, unknowable.

While few in number, there are documents that prescribe visions for engineering education. These reports are willing to make sweeping generalizations. Unfortunately, these generalizations are entirely unsubstantiated. These reports have been the only guidance given to the profession over the last 50 years. Therefore, engineering education has been evolving based solely on supposition and belief. It is little wonder that the engineering education literature has been identifying the same weaknesses and suggesting the same remedies for all this time.

As an innovative approach to engineering and engineering education, the department of Systems Design Engineering was 30 years ahead of its time. Its success is evidenced by the aspects of its curriculum that have slowly but steadily become central to modern engineering education. The introduction of systems, design, and complexity into the undergraduate curriculum has produced engineers that meet and exceed the requirements of industry and the profession. Systems Design stands alone in Canada and with few peers abroad as a candidate for the new funding for research into these areas.

As innovative and successful as Systems Design Engineering has been, it has failed to meet many of its design goals. The department curriculum no longer pays significant attention to the details of design or system theory. The faculty members do not exhibit the characteristics of an integrated group with a shared purpose. Interference from its host faculty and a lack of resources constrained the curricular and structural innovations that could be implemented. When this was coupled with the understandable lack of trained faculty, it is unsurprising that the department was unable to effect the radical shifts or internal cohesion it desired. Today it remains difficult to find faculty members qualified to teach the courses in systems, complexity, and design that are so vital for continued success.

Systems Design displays a lack of continuing cohesive vision. This failure is common to both the institutions of higher education and the engineering profession and underlies many of the issues currently facing both higher education and engineering education. The lack of a cohesive vision within the department has kept it from realizing its full potential. The department of today is a fragmented, balkanized shade of both its former glory and its design potential. Whether those who would follow in the footsteps of the department can avoid its fate remains to be seen. To date their attempts show few portents of success.

Both higher education and engineering education are about to undergo a renaissance. This renaissance will bring with it new commitments and directions from government, universities, and the profession. The design goals and experiences of Systems Design Engineering provide a glimpse of a possible future for engineering and engineering education. It is vital that engineering, and its educators, escape from the narrow confines of tradition to embrace an expanded social role. Universities must also recast themselves in terms of the social purpose that led to their creation. For this renaissance to succeed, a new framework for conceiving of engineering and engineering education must be developed.

Given the primitive state of formal research into engineering education there are many opportunities for future research. With respect to framing the discussions of engineering education, possible future research includes:

- An anthropological study that treats engineers an a distinct culture.
- A full Soft Systems Study of engineering and engineering education involving visionary engineers and educators.
- A study of CEAB records to determine how and why the accreditation criteria have evolved.
- A study of the responses to the question "Why do you want to become an engineer?" produced by applicants to engineering programmes[1].

With respect to developing an understanding of the current and desired future states of engineering education, possible future research includes:

- A study that correlates company press releases with entry-level hiring practices.
- A study of the follow-up work associated with the various proposals for engineering education.
- A survey of the teaching techniques used in introductory and advanced design courses across Canada.
- A study of the impact of these courses and teaching techniques on the design abilities of graduate engineers.

With respect to developing a formal research programme in engineering education, possible future research includes:

- Interviewing past professors in Systems Design Engineering who taught systems, complexity, and design to determine what teaching techniques they used.
- Investigating the applicability of the European standards for engineering education and engineering educators in the North American context.

[1]This study can easily be performed at the University of Waterloo where all engineering applicants complete a Personal Information Forms that includes similar questions.

- A study of the evolution of introductory engineering texts with the purpose of determining when and why systems concepts were removed.

With respect bringing forth the visions of higher and engineering education expressed in chapter 6, possible future research includes:

- Developing an organizational structure that supports the vision for higher education.
- Developing a new engineering curriculum that supports the vision for engineering education.

This thesis provides an overview of engineering education suitable for any aspiring researcher in this field. It demonstrates that there is both the need and the opportunity for significant contributions to be made. The future of engineering and engineering education rests in the hands of those who take up the challenge to reinvent this most vital of professions.

Appendix A

Scouting the engineering education territory

This appendix describes the engineering education resources which should be of interest to other researchers. The resources in each category are divided into tiers. This division is based on my subjective ranking of the resource. Tier One resources are those that are both directly relevant to engineering education and easy to obtain. Resources from the lower tiers provide additional information to supplement that of the upper tiers. In a number of cases promising resources were reduced in rank because of difficulties in locating and obtaining the resource. Section 6.9.1 discusses a number of individuals who have made significant contributions to engineering education

A.1 Non-governmental organizations

A.1.1 Focused on engineering education

Tier One

- American Society for Engineering Education (ASEE)

Tier Two

- Canadian Engineering Accreditation Board (CEAB)
- Accreditation Board for Engineering and Technology (ABET)
- Canadian Engineering Qualifications Board (CEQB)
- International Society for Engineering Education (IGIP)
- European Society for Engineering Education (SEFI)
- National Council of Deans of Engineering and Applied Science (NCDEAS)
- Engineering Deans Council (EDC)
- $\Sigma\xi$
- UNESCO International Centre for Engineering Education (UICEE)
- The Professional and Organizational Development Network in Higher Education (POD)

Tier Three

- Society for Teaching and Learning in Higher Education (STLHE)
- Canadian Federation of Engineering Students (CFES)
- $\tau\alpha\pi$

The ASEE is by far the dominant organization in engineering education. They are responsible for organizing a number of the more popular conferences and for publishing two of the more popular journals. The ASEE also investigates and publicises the state of engineering education. They have published the Grinter and Green reports as well as annual profiles of engineering colleges. In addition they sponsor a number of awards that promote engineering education and act in an advocacy role. The ASEE also acts as an umbrella organization for a number of related groups such as the EDC. The ASEE is also extremely open and organized with respect to providing information and materials to interested parties.

The national accreditation boards both have tremendous influence on the content of an engineering education and to a lesser degree on how that content is delivered. Both accreditation boards provide their formal criteria in a forthcoming manner to any interested party. The accreditation boards are assisted in their efforts by organizations that provide details specific to particular engineering disciplines. In Canada the CEQB has developed the Examination Syllabus that defines the core and supplementary bodies of knowledge for 17 engineering disciplines. In the United States similar information is provided to ABET for 24 disciplines by organization such as the Institute of Electrical and Electronics Engineers (IEEE) and the American Society of civil Engineers (ASCE).

From the perspective of the public the CEAB produces a single document, the *Accreditation Criteria and Procedures*. The criteria described in this document focus on curriculum and on programme environment. The CEAB has no documentation to explain the rationale behind their criteria. Additionally section 3.3 of the *Accreditation Criteria and Procedures* refers to a questionnaire that programme must complete and remit before the accreditation visit. This document is not made available to the general public. ABET is significantly more forthcoming with their documentation. In addition to their criteria they publish accreditation manuals, policies, and guides. ABET also publishes ancillary documents discussing engineering ethics.

The accreditation organizations do not, and likely cannot, provide any public justification for their respective criteria. This inability is worrisome given the influence these criteria have on engineering education. Similar concerns can be voiced regarding the discipline-specific criteria provided by the CEQB and the societies and institutes. Some of these concerns stem from an apparent lack of interest on the part of engineering educators. According to the CEAB secretariat prior to this research there have been no requests for such justification. The only potential source for this information is the collected minutes of the accreditation board meetings. Wading through these minutes is a future direction for this research.

From the perspective of enhancing engineering education IGIP is by far the world leader. Among its activities is the formal training and registration of engineering educators. Since 1988 engineers in Europe have been able to attend a year long training programme, oriented around a formal engineering pedagogy developed by SEFI. When coupled with a year of teaching experience the applicant is awarded the related titles of "ING-PAED IGIP" and "European Engineering Educator". This accreditation programme is globally unique.

SEFI is a 30 year old network of European institutions and individuals involved in engineering education that supports the work of IGIP. The key roles of the network are advocacy for engineering and engineering education and linking its members to other societies and international bodies.

The two councils of engineering deans also exert influence on engineering education by virtue of their composition. Both groups tend to work in the background or in partnership with other parties to produce position papers and reports. The NCDEAS is composed of the 34 Canadian deans of engineering. It has no permanent staff, budget, or facilities. Accordingly it has no presence on the WWW nor does it have a publications archive. As a group hosted by the ASEE the EDC has access to significantly more resources than the NCDEAS. $\Sigma\xi$ fills a similar role as the two councils, albeit with a less restricted membership composed of scientists and engineers.

The UICEE is a relatively new organization with the potential to have a significant impact on engineering education. As things stand the global engineering education community is divided among the ASEE, SEFI, and the UICEE. Of the three only the UICEE is active among the nations with an increasing population of engineering undergraduates. Engineering educators from Asia, Africa, the former USSR, and South America are significantly more likely to be found at UICEE events or in UICEE journals. The UICEE is also the only organization of the three that is expending significant energy towards expanding its operations. Should international mobility continue to increase the UICEE may plan an even larger role in mediating between the different national and supra-national accreditation bodies. At present the quality of the material in the UICEE publication and at its conferences is somewhat below that of the ASEE or SEFI. This situation is changing rapidly as the engineering education communities of the UICEE constituents mature.

CFES and $\tau\alpha\pi$ are both represent the undergraduate engineering student body. This is an important constituency that is not represented by any other organizations. Unfortunately the quality and quantity of the materials produced by these two organizations is comparatively poor. However they are currently, and are likely to remain for the foreseeable future, the only sources of publicly documented student opinions on engineering education.

There are many smaller organizations that address engineering education. These organizations differ from those listed above in that they tend to focus on the needs of a particular group or location. Examples of the mandates of such organizations include promoting engineering to female applicants and enhancing engineering education among a small group of proximate institutions. Such organizations tend to focus more on the application than on the generation of theory. They also tend to be more short lived and their publication are generally more difficult to obtain. Accordingly they are not suited for an overall map of the engineering education territory.

A.1.2 Focused on engineering

Tier One

- Canadian Council of Professional Engineers (CCPE)
- Canadian Academy of Engineering (CAE)
- Engineering Institute of Canada (EIC)

Tier Two

- Provincial Engineering Associations
- Discipline-specific organizations

The organizations that fall into this category are generally concerned with engineering as a profession. They are interested in engineering education primarily as a vehicle for enhancing or regulating the profession. Accordingly their influence on engineering education is less direct than that of the organization described in A.1.1. Some of the organizations also act in a advocacy role. Advocacy has the potential to impact on engineering education, for example by changing the type of students who apply to engineering programmes.

The CCPE interacts with engineering education primarily through two of its constituent boards. The activities and importance of the CEAB and the CEQB were discussed in A.1.1. The CCPE also has influence on engineering education through its efforts to define and regulate the profession and activities of engineering. Unlike the CEAB, the CCPE does explicitly define engineering. This definition has the potential to affect the programme specific information generated by the CEQB and eventually the individual engineering programmes.

Among all of the organizations mentioned in this chapter the CAE is most directly concerned with the economic aspects of engineering. Since its founding in 1987 the publications of the CAE have increasingly focused on issues such as commercialization and technical entrepreneurship.

> "The mission of the Canadian Academy of Engineering is to enhance, through the application and adaptation of science and engineering principles, the promotion of wellbeing and the creation of wealth in Canada."

The organization does not hide this focus on economic issues. However it has made no public mention of any non-economic activities spearheaded by the organization over the last 3 years. In the past the CAE has done an outstanding job of ensuring that its contributions are available to the wider public. For this reason it is alarming that the CAE appears to have stopped updating its web presence in June of 2000.

The EIC has the potential to become an important contributor to undergraduate engineering education. Beyond serving as a point of contact for its constituent members, the EIC has chosen to address the issue of continuing engineering education and professional development. At present these activities are outside of the scope of undergraduate engineering education. This boundary is being maintained by the actions of the larger provincial engineering regulating organizations. These organizations have not chosen to enforce a continuing competence or education regime. Accordingly there is no official need for undergraduate engineering programmes to prepare their students for lifelong learning. Should the regulatory organizations choose to change their positions on this issue there will be an impact on undergraduate engineering education. Under these circumstances the role and importance of the EIC will increase.

The provincial engineering regulatory bodies have allowed the CCPE, primarily through the CEAB, to address many of the issues related to engineering education. Where the provincial bodies currently retain an active role is through the professional practice exams[1]. These exams require knowledge of engineering ethics and law. This content is, in theory, integrated into the curricula of accredited engineering programmes[2]. The provincial bodies also affect current engineering education in a minor way through their programmes to attract students to the profession after graduation. A seemingly unknown fact is that there is nothing to stop a provincial regulatory body from developing its own engineering

[1] The exact name and nature of the exams differs from province to province.

[2] My undergraduate engineering education covered neither engineering law nor engineering ethics.

accreditation scheme. While such an act would go against tradition it remains a possibility. This potential flexibility would allow an institution to develop an engineering programme that would not meet the CEAB criteria but that would meet the provincial criteria. To date there is no available evidence to suggest that a programme has pursued this alternate avenue to accreditation.

In Canada, discipline-specific engineering organizations like the Canadian Societies for Civil or Mechanical Engineering (CSCE, CSME) tend to affect engineering education indirectly through their contributions to EIC activities. Should the CCPE adopt a model similar to that of ABET these organizations would take on a significantly larger role in defining engineering curriculum. There is no evidence that the CCPE or the organizations are considering this change. However, the ABET model may be adopted in the future as a mechanism to deal with the emerging disciplines such as software engineering. In this case, the discipline-specific organizations will assume a larger role in defining engineering curriculum.

A.2 Governmental organizations

Tier One

- National Science Foundation (NSF)
- National Research Council (NRC)
- National Academy of Engineering (NAE)

Tier Two

- Natural Science and Engineering Research Council (NSERC)
- Social Science and Humanities Research Council (SSHRC)
- Commission on Engineering and Technical System (CETS)
- National Science Foundation Division of Undergraduate Education
- National Academies Center for Science, Mathematics, and Engineering Education

With respect to research into engineering education, governmental organizations tend to be of marginal value. These organizations have produced a number of important reports and initiatives. However these reports are in most cases generated by issue-based, short-lived committees or centres. There do not seem to exist any governmental organizations who have been investigating engineering education for any protracted periods of time. This transience implies that engineering education is generally treated by government agencies as a short-term, tactical initiative. Whether this attitude will change in response to the recent report of the the U.S. Commission on National Security/21st Century remains to be seen.

The Tier One sources listed above are the parent or sponsor organizations of the various committees. They have remained relatively permanent while the various committees have been formed and disbanded. Unfortunately from the perspective of the researcher into engineering education these organizations also cover a broad spectrum of activities. Their most useful aspects are their publication archives. All three organizations have made the majority of the reports generated by their various sub-units available to the public over the web. It is unfortunate that there are no Tier One Canadian organizations.

The Tier Two sources can be divided into two categories. The first category consists of funding agencies. Along with all of the Tier One agencies, NSERC and SSHRC are possible funding sources for researchers into engineering education. At present the funding situation differs markedly between the two countries. In the United States there are a number of funding initiatives devoted explicitly to improving engineering education. There are also a number of awards that recognize outstanding engineering educators. In Canada there is only this second type of funding. Neither NSERC nor SSHRC is willing to find researching into engineering education. In both cases this decision may be at odds with their respective mandates.

SSHRC has a funding group devoted to research into education. This group however is extremely reluctant to fund research into discipline-specific issues or into undergraduate-level students. SSHRC prefers to fund research into the developmental aspects of childhood education. Repeated requests for clarification as to the genesis of this approach to funding research into education met with no reply. For its part NSERC refuses to fund any research into engineering education. While it is willing to recognize outstanding educators and to include education as a duty of its funded chairs, it is not willing to devote funds towards researching the topic. NSERC describes its mission in part as being "...to provide the largest possible number of Canadians with leading-edge knowledge and skills …". The lack of research into engineering education belies a comprehensive approach to meeting this goal.

NSERC also exerts influence on engineering education by controlling in large part which faculty members, and by extension which programmes, will receive research grants. It is difficult to attract faculty members, regardless of their teaching abilities, to a Canadian programme that does not receive NSERC funding. This difficulty is particularly acute in non-traditional science or engineering disciplines. NSERC does not appear to have a formal discovery process that targets non-traditional fields. Accordingly NSERC funding for a field seems difficult to acquire but equally difficult to lose. There are established engineering programmes in Canada, such as Systems Design Engineering, that represent established engineering fields yet continue to lack an NSERC grant selection committee.

The second category of Tier Two sources are a selection of the more relevant groups formed by the Tier One sources to investigate engineering education. These groups are currently active and maintain active research programmes.

A.3 Journals, lists, and serials

Tier One

- Journal of Engineering Education (JoEE)
- Chemical Engineering Education (CEE)

Tier Two

- PRISM Magazine
- IEEE Transactions on Education (ToE)
- Journal of Professional Issues in Engineering Education and Practice (JPIEEP)
- International Journal of Mechanical Engineering Education (IJMEE)

Tier Three

- International Journal of Engineering Education (IJEE)

- Global Journal of Engineering Education (GJEE)
- European Journal of Engineering Education (EJEE)
- Australasian Journal of Engineering Education (AJEE)

Generalizing slightly, all engineering education journals appear to share a common article format. This format could colloquially be called "What I Did With My summer Vacation." The vast majority of the articles in these publications follow the following pattern:

1. Discussion of a gap/flaw/problem associated with a particular course at a particular institution (e.g.. Our design course isn't teaching design)
2. Presentation of a plan to address the issue where the plan is based neither on theory nor on precedent (e.g.. We chose to use a competition-based approach involving project teams)
3. Discussion of implementation details (e.g.. The groups were composed of between 8 and 10 randomly selected students; The competition challenge was to build a kinetically-powered vehicle)
4. Presentation of results (e.g.. The students built interesting devices that met the competition challenge)
5. Discussion of a satisfaction measurement based neither on theory nor on precedent (e.g.. We created a survey to measure student satisfaction and learning)
6. Conclusion that the plan was a good one (e.g.. The survey results showed that the students enjoyed the course)

Ideally this depiction would be a caricature. To some degree it is. However the vast majority of the journal articles do suffer from the common flaws identified in the meta-analysis performed by Wankat (see section 4.1). There is an emerging trend away from this caricature. A small number of the the general engineering education journals have explicitly recognized the need for increased theoretical rigour in engineering education.

> "If the *Journal of Engineering Education* is to attract significant attention, it must contain scholarly articles possessing enunciation of education principles, not simply superficial analyses of classroom data or experiments." [94]

> "The *International Journal of Engineering Education* has recently decided to accord more emphasis to engineering education research that has a clear theoretical and conceptual basis, and that reports results that have wider application to teaching practice and student learning." [149]

Based on the meta-analysis of the JoEE and on an informal assessment of the IJEE, the ToE, and the remaining publications no publication has been able to successfully maintain a focus on educational theory. However all of the journals do include the occasional paper where theory takes a central role. More rare are papers where accepted research methods have been properly followed to test the theories. Engineering educators are by and large trained as engineers first. If they are trained as educators at all, this training comes second. Any training in educational research, which appears to be all but absent among engineering educators, comes a distant third. Accordingly the vast majority of engineering educators are unfamiliar and inexperienced with the research methods applicable to education research. The fact that approximately half of the engineering education authors come from a non-technical background may in fact be improving the overall quality of the research into engineering education.

An an ASEE publication the JoEE enjoys a deserved reputation as the dominant engineering education publication. When its previous incarnation as Engineering Education (EE) is taken into account it is the longest continuously published engineering education journal. In 1992, EE was split along audience lines into the JoEE and PRISM. The JoEE was intended to appeal to researchers and scholars while PRISM was focused on faculty, administrators, and industry and government representatives. [214] Since its introduction the JoEE has maintained a relatively wide variety of topics. However through much of the late 1990s the focus of the JoEE was on the imminent introduction of the ABET 2000 accreditation criteria.

Based on its editorial policy the JoEE is not meeting all of its objectives. The vast majority of its articles fall into the category of "describe intra-institutional, inter-disciplinary efforts within a university... leading to enhancement of engineering education." Why the other desired categories, most importantly "describe what we can learn from our history, such as how the seminal papers and reports of the past impacted engineering education and led to what it is today", have not been filled is an unanswered, and apparently unasked within the pages of the journal, question.

The ASEE also publishes CEE. One might assume that the CEE, being specific to a single discipline and competing with the JoEE, would be a tier two journal. In fact many of the more well known engineering educators, such as Wankat, come from chemical engineering[3].

The final ASEE publication of interest is PRISM. It is a tier two journal only because it treats its issues in a less formal manner than the JoEE. Accordingly it is less relevant to the researcher in engineering education. Otherwise it is deserving of tier one status for two reasons. First, because it covers a broad spectrum of the issues related to engineering education. Second, and more importantly, because PRISM informs those who are in a position to effect change in engineering education. Accordingly this magazine provides insights into the positions and concerns policy makers and heads of departments are likely to have with respect to engineering education.

Discipline-specific engineering education journals suffer from an enhanced version of the shortcomings of the tier one journals. The three most established of these journals, ToE (electrical engineering), JPIEEP (civil engineering), and IJMEE (mechanical engineering), all focus almost exclusively on engineering education activities that have no basis in educational theory. Where these journals are relevant is in acquiring a feel for the established practices in the various disciplines. The contrast between these journals and CEE is interesting. All of these journals are intended to focus on a particular discipline. Only authors from CEE seem to include sufficient theoretical content to become widely known in the field of engineering education.

An important development with respect to ToE occurred in May, 2001. After substantial changes to the editorial team the role and scope of the journal were changed significantly. For example, the publishers stated that they were not interested in reviewing papers with "…Significant technical content with little or no substantive pedagogic information." This change is recent enough that its effects are not known. It will be interesting to observe whether the ToE can succeed where the JoEE has failed.

[3] In an interesting coincidence many of the prominent systems thinkers researchers and educators also come from chemical engineering. By going through Systems Design engineering I may have missed something important to my research.

The tier three journals offer little new information to supplement the upper tier journals. They do however offer an alternate perspective on many engineering education issues.

A.4 Conferences

Tier One

- Frontiers in Education (FIE) – ASEE
- Annual Conference – ASEE

Tier Two

- Canadian Conference on Engineering Education (C^2E^2) – NCDEAS
- Engineering Deans Institute – ASEE
- Annual Conference on Engineering Education – UICEE

Tier Three

- Industry, University, Government Roundtable for Enhancing Engineering Education (IUGREEE) – ASEE
- Engineering Research Council Summit, Workshop & Forum – ASEE
- Engineering Deans Council Public Policy Colloquium – ASEE
- Conference for Industry and Education Collaboration ASEE
- Baltic Region Seminar on Engineering Education – UICEE
- Asia-Pacific Forum On Engineering And Technology Education – UICEE

As with all aspects of engineering education, the ASEE dominates the conference scene. The two ASEE conferences, FIE and the Annual Conference, are acknowledged as the primary venues for networking and for developing an appreciation for the state of engineering education. Consisting of plenary speeches, sessions, and poster presentations, the FIE is the more academically oriented of the two conferences. Both commercial vendors of academic materials and academics make presentations at the Annual Conference. Most FIE and Annual Conference papers are between four and six pages in length with few references. Of the small number of references, few refer to formal theory. Since 1993 the size of the FIE conference, as measured by the number of papers presented, has grown dramatically.

As the only semi-regular Canadian conference the C^2E^2 must be included as a tier two source. Unfortunately the C^2E^2 is smaller and less well attended than all of the other conferences, including those in tier three. The C^2E^2 has been organized by the NCDEAS. As a result it suffers from a lack of resources. Organizing the conference is not a formal part of the duties of the organization or its members, so it is usually held during those years when the NCDEAS president is both interested in and willing to chair the event.

The remaining conferences in tiers two and three are either devoted to special interest groups within engineering education or are outside of the North American scope.

All of the engineering conferences suffer, to greater or lesser degrees, from a similar problem. The conferences are dominated by senior engineering faculty and university administrators. At the most recent UICEE Annual Conference, I was the only graduate student in attendance. The conference papers, even more than journal articles, follow the "what I did with my summer vacation" structure. The Deans and senior faculty tend to tout the activities of their institutions and programmes without theoretical support. The FIE and the ASEE Annual Conference have acknowledged that restricted attendance is an issue and have developed programmes to encourage students and new faculty to attend.

Appendix B

Popular media

It is rare that a day goes by without the publication by the popular media of an article related to technical education. The following is a selection of articles that caught my eye while I was writing this thesis.

We'll pay a price down the road for today's school cuts "Good schooling, [companies] realize, contributes to Canada's economic growth. More pertinently, it contributes to the future success of their own businesses..." [168]

Brain gain: the ABCs of dot-com "Curriculums must include the 'new basics' of teamwork and computer skills alongside the three Rs, or we'll all lose out, says BSE's Jean Monty." [177]

The school of Harry Giles "Harry Giles has little time for Ontario's education system. At his school...students complete the equivalent of a high school degree in Grade 8 - five years ahead of their public school counterparts." [4]

Entrepreneurs then and now: the same old struggle "The role of entrepreneurs is to transform an unpredictable universe into a predictable one[1] for their employees, their customers and their suppliers. If they can manage that their business is successful. If they fail, so does their business. This was true fifty years ago, and it's true today." [19]

High-tech CEOs voice support for financing liberal-arts studies "A growing fix-

[1]See section 6.12.7 for a discussion of why this goal may be unattainable.

ation with technology instead of the arts in higher-education financing, most notably by the Ontario government, has run into an unexpected challenge by the very industries it is supposed to benefit." [198]

The Importance of Teaching "We are all in favour of education, but we tend to take for granted the people who provide it. If our society cares about the future, it will resume giving teachers the support and credit they deserve." [193]

Will there be enough excellent profs? "The university sector in Ontario has a very limited capacity to meet the large projected rise in enrolment through more intensive use of the present faculty complement, if the quality of higher education in Ontario is to be sustained." [222]

How will I know if there is quality? "Ontario's universities are at a critical juncture in the quality of their work. In striving to enhance quality, they face major challenges." [221]

The Digital Brain Drain – So Many Computers, So Little Interest in Hard Science "...But a sense is growing in some business quarters that the sheer ubiquity of computers has deflected attention from more traditional sciences and skills." [83]

Go figure, Ashley can't "In grade 4 they're doing fractals. But they don't even seem to have the basics down. ...It also turns out that most kids prefer certainty to guesswork. 'It gives them security that they're headed in the right direction,' says John Mighton. A bewildered student told his teacher, 'We go to school so that you can teach us. Why should we teach ourselves when we have you?' ." [275].

Digital Diploma Mills: The Automation of Higher Education "[Automation] is assumed to improve learning and increase access. In practice, however, such automation is often coercive in nature - being forced upon professors as well as students - with commercial interests in mind...It is not a progressive trend towards a new era at all, but a regressive trend, towards the rather old era of mass-production, standardization and purely commercial interests." [182]

Brave New B.A. "The new undergraduate curricula of Canadian universities are increasingly concerned with providing [exposure to a broad spectrum of disciplines and learning approaches] through interdisciplinary studies, smaller classes, an emphasis on explicit statements of required learning outcomes and skills, and subject matter and teaching techniques that are 'more obviously meaningful for the student.'." [56]

Reengineering the University "Today's university is at a turning point and turn it must. The time has come to recognize that education is a business and students are the customers... Professors are personnel who produce and evolve content. They are needed only to the extent that a university produces content in the area. Their number can be greatly reduced, but they need to be talented both as specialists and as lecturers in order to compete globally." [245]

Appendix C

Meta-assessments

C.1 Assessing the assessment model

The primary purpose of the assessment model presented in section 3.2 is to determine the strengths and weaknesses of the sources that inform this thesis. The criteria are sufficiently general that they could be used to assess most documents and models. Accordingly a good test of the assessment model is to use it to assess itself. Figure C.1 shows the results of assessing the model and its and discussion of the assessment follows.

Scale The model is presented as a composite of a number of different scales. Accordingly the majority of the discussion it at the *narrow system* level. The increasing arrow represents the relatively infrequent references to wider issues such as epistemology and ontology. The decreasing arrow acknowledges that the majority of the discussion focuses on details of the various scales.

Type By virtue of deciding on a set of targets for the criteria, the majority of the discussion cannot exceed the *authoritarian* level. Because other perspectives are mentioned, although not adopted or discussed in detail, the ranking is pushed to the *authoritarian* level.

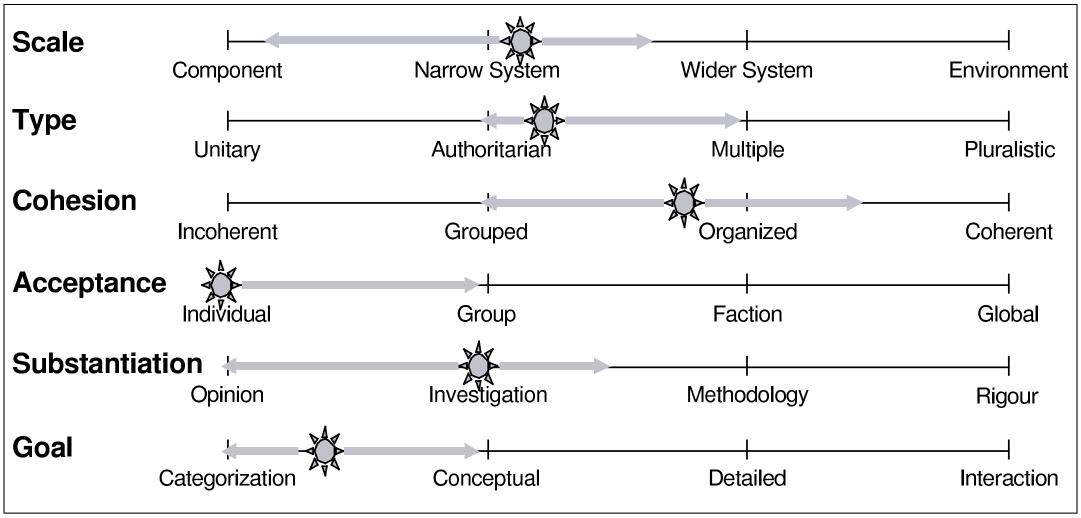

Figure C.1: Assessment of the categorization model

Cohesion The introduction of the model is reasonably focused. The discussion is organized in a linear fashion, but the rationale behind the ordering is not made known. Accordingly the cohesion scores an *organized*.

Acceptance This model exists only within this thesis. Accordingly only the author is guaranteed to have accepted it. Should the thesis be accepted the readers will increase the acceptance to the level of *group*.

Substantiation The model and discussion were developed after a relatively long period of investigation. Some aspects, in particular the target criteria, are based solely on opinion. This is offset by the use of accepted terminology in the *scale* and *type* axes.

Goal By virtue of acknowledging the interactions of several components, this model demonstrates a higher level of organization than simple *categorization*. However, the absence of any rigorous theoretical basis means that the model does not meet the standards associated with *conceptual*.

C.2 Assessing the the "standard" engineering model of engineering education

The "standard" engineering model of engineering education described in section 3.6.1 can be evaluated using the assessment model described in section 3.2. The results of this assessment are presented in figure C.2 and described below.

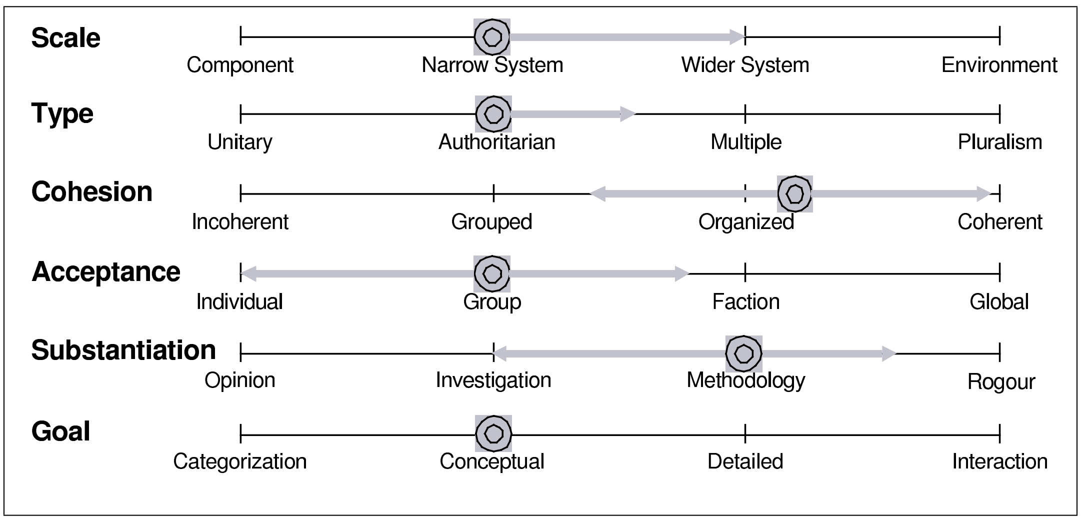

Figure C.2: Assessment of the engineering process model of engineering education

Scale The engineering process model deals only with a subset of the activities performed within an engineering department. While it does include infrastructure as a parameter, this is no sufficient to score more than a *narrow system*.

Type This model was develop using a standard engineering approach to process modelling. It does include items, such as goals, that may not be a part of an engineering model. It also makes use of terminology from systems theory. Given that this extra information is mostly subordinate to the engineering perspective the model scores an *authoritarian*.

Cohesion The use of a single type of model allows the engineering process model to remain very coherent. In conjunction with the relatively high level of substantiation this model scores an *organized*.

Acceptance The process model that underlies this model is relatively well accepted. The application of this type of model to social issues such as education is much less accepted. As a component of this thesis, positing acceptance, the model scores a *group*.

Substantiation The process model is accepted within engineering and therefore is acceptable as a *methodology*. Those aspects of the model that come from other disciplines, and that accordingly may not fit the assumptions of the engineering model, reduce the score.

Model Given that it includes a formal representation of the components and relationships this model scores a *conceptual*.

C.3 Assessing this thesis

Ideally this thesis will be a useful reference for individuals who are interested in learning more about engineering education. One way to gauge how well this goal has been met is to subject the thesis to the assessment model presented in chapter 3.2. Figure C.3 summarizes the assessment of this thesis.

Scale The discussion of scope in section 1.2 limits this thesis to discussions of the *narrow system*.

Type To demonstrate the lack of cohesion and the need for a research community into engineering education this thesis endeavours to provide multiple perspectives on the issues. Accordingly the majority of this thesis rates a *multiple*. On occasion discussion will be cut short for reasons of expediency, leading to the decreasing arrow.

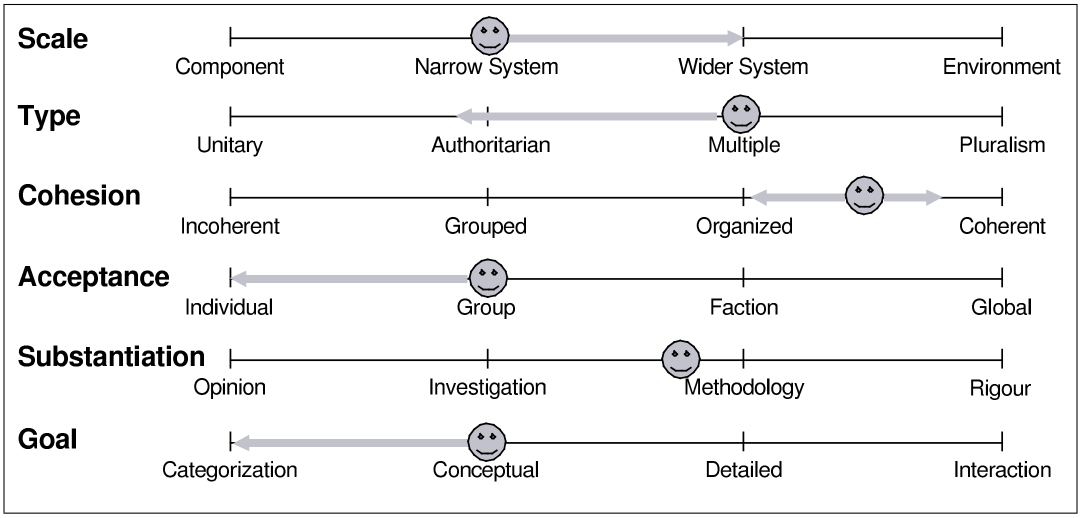

Figure C.3: Assessment of this thesis

Cohesion The thesis has a definite structure and flow. Although it does meander on occasion, quite possibly in discussing itself, it nevertheless rates slightly more than an *organized*.

Acceptance Assuming that the thesis is accepted it will rate a *group*.

Substantiation This thesis is primarily composed of literature reviews, syntheses, and opinions. Accordingly it scores close to a *methodology*.

Model As an overview this thesis is not intended to proceed to interaction or to a detailed model. The lack of existing research and the time and space constraints on occasion push this thesis towards a *categorization*.

Whether the thesis rates these scores is for the reader to decide.

Appendix D

Distinguished accredited engineering programmes

Many North American engineering educators, who oppose accreditation, believe that the top engineering schools in the United States are not accredited. The following excerpt from the ABET list of accredited engineering programmes[1] demonstrates that this is not the case. The list is ABET list of accredited schools and programmes demonstrates that this is not the case. The dates following each programme name indicate the date that the programme was first accredited. In the interests of brevity some programmes have been removed from the individual school lists.

- California Institute of Technology
  - Chemical Engineering (1936)
  - Electrical Engineering (1997)
  - Engineering and Applied Science (1964)
- University of California, Berkeley
  - Chemical Engineering (1952)
  - Civil Engineering (1936)
  - Computer Science and Engineering (1983)

[1] `http://www.abet.org/accredited_programs/EACWebsite.html` (2001-08-02)

  - Electrical Engineering (1936)
  - Industrial Engineering (1949)
  - Mechanical Engineering (1936)
  - Nuclear Engineering (1983)

- Carnegie Mellon University
  - Chemical Engineering (1936)
  - Civil Engineering (1936)
  - Electrical and Computer Engineering (1936)
  - Materials Science and Engineering (1936)
  - Mechanical Engineering (1936)
  - Engineering and Public Policy (1989)

- Case Western Reserve University
  - Aerospace Engineering (1995)
  - Biomedical Engineering (1977)
  - Chemical Engineering (1936)
  - Civil Engineering (1936)
  - Computer Engineering (1971)
  - Electrical Engineering (1936)
  - Fluid and Thermal Engineering Science (1971)
  - Materials Science and Engineering (1936)
  - Mechanical Engineering (1936)
  - Systems and Control Engineering (1971)

- Cornell University
  - Chemical Engineering (1936)
  - Civil Engineering (1936)
  - Electrical Engineering (1936)
  - Engineering Physics (1951)
  - Materials Science and Engineering (1951)
  - Mechanical Engineering (1936)

- Operations Research and Engineering (1936)
- Dartmouth College
  - Engineering (1936)
- Drexel University
  - Architectural Engineering (1991)
  - Chemical Engineering (1936)
  - Civil Engineering (1936)
  - Electrical Engineering (1936)
  - Materials Engineering (1953)
  - Mechanical Engineering (1936)
- George Mason University
  - Electrical Engineering (1986)
  - Systems Engineering (1995)
  - Urban Systems Engineering (1995)
- Georgia Institute of Technology
  - Aerospace Engineering (1936)
  - Chemical Engineering (1938)
  - Civil Engineering (1936)
  - Computer Engineering (1991)
  - Electrical Engineering (1936)
  - Industrial Engineering (1949)
  - Materials Science and Engineering (1942)
  - Mechanical Engineering (1936)
  - Nuclear Engineering (1975)
- Harvey Mudd College
  - Engineering (1962)
- Massachusetts Institute of Technology

- Aeronautics and Astronautics (1936)
- Chemical Engineering (1936)
- Civil Engineering (1936)
- Computer Science and Engineering (1978)
- Electrical Engineering and Computer Science (1996)
- Electrical Science and Engineering (1936)
- Materials Science and Engineering (1936)
- Mechanical Engineering (1936)
- Nuclear Engineering (1980)

• Pennsylvania State University

- Aerospace Engineering (1949)
- Architectural Engineering (1936)
- Chemical Engineering (1936)
- Civil Engineering (1936)
- Computer Engineering (1991)
- Electrical Engineering (1936)
- Engineering Science(s) (1959)
- Industrial Engineering (1936)
- Mechanical Engineering (1936)
- Nuclear Engineering (1973)

• Purdue University at West Lafayette

- Aeronautical and Astronautical Engineering (1944)
- Chemical Engineering (1936)
- Civil Engineering (1936)
- Computer Engineering (1984)
- Construction Engineering and Management (1984)
- Electrical Engineering (1936)
- Industrial Engineering (1960)
- Materials Science and Engineering (1941)
- Mechanical Engineering (1936)

- Nuclear Engineering (1978)

- Rensselaer Polytechnic Institute
  - Aeronautical Engineering (1938)
  - Biomedical Engineering (1972)
  - Chemical Engineering (1936)
  - Civil Engineering (1936)
  - Computer and Systems Engineering (1978)
  - Electric Power Engineering (1972)
  - Electrical Engineering (1936)
  - Engineering Physics (1993)
  - Industrial and Management Engineering (1978)
  - Materials Engineering (1938)
  - Mechanical Engineering (1936)
  - Nuclear Engineering (1966)
- Swarthmore College
  - Engineering (1936)
- Texas A & M University
  - Aerospace Engineering (1942)
  - Chemical Engineering (1946)
  - Civil Engineering (1936)
  - Computer Engineering (1993)
  - Electrical Engineering (1936)
  - Industrial Engineering (1949)
  - Mechanical Engineering (1936)
  - Nuclear Engineering (1969)
- Tufts University
  - Chemical Engineering (1952)
  - Civil Engineering (1936)

- Computer Engineering (1982)
- Electrical Engineering (1936)
- Mechanical Engineering (1936)

Appendix E

Accredited "systems" programs

This appendix demonstrates that systems theories have been embraced to some extent by a number of accredited engineering programmes. The information presented in this appendix is taken from the ABET web site[1] and the CEAB accreditation report for 2000. [32] Some of the programme categories, for example "Agricultural and Biosystems Engineering" and "Biosystems Engineering" likely share similar characteristics and orientation. However as they are separated by the accreditation bodies they remain separate here.

The programmes that are most likely to share the most characteristics with the vision presented in this thesis are "Systems Analysis and Engineering", "Systems Design Engineering", "Systems Engineering", and "Systems Science and Engineering". Without investigating each programme individually it is not possible to know what content each programme provides. Neither the CEQB, and by association the CEAB, nor ABET provide details for any of these programmes. These details are generally provided only for more traditional engineering disciplines. The omission of a detailed description of systems programs is interesting in light of the fact that systems-related programmes have been accredited since the 1950s and systems-specific programmes since the mid-1970s. In the case of ABET the "program criteria", that specify the curriculum for a programme, are submitted by engineering institutes and societies. This implies that the International Council on Systems Engineering (INCOSE) has chosen not to submit criteria for systems engineering and related disciplines.

[1] `http://www.abet.org/accredited_programs/EACWebsite.html` (2001-08-02)

- Agricultural and Biosystems Engineering
  - University of Arizona (Bachelor's,1960)
  - North Carolina Agricultural and Technical State University (Bachelor's,1991)
- Biological Systems Engineering
  - University of California (Bachelor's,1965)
  - University of Idaho (Bachelor's,1996)
  - University of Nebraska-Lincoln (Bachelor's,1994)
  - Virginia Polytechnic Institute and State University (Bachelor's,1981)
  - Washington State University (Bachelor's,1996)
- Biosystems Engineering
  - Clemson University (Bachelor's,CoOp,1953)
  - University of Hawaii (Bachelor's,2000)
  - University of Manitoba (1996)
  - Michigan State University (Bachelor's,CoOp,1950)
  - Oklahoma State University (Bachelor's,1950)
  - University of Tennessee at Knoxville (Bachelor's,CoOp,1964)
- Civil Engineering Systems
  - University of Pennsylvania (Bachelor's,1936)
- Computer Systems Engineering
  - Arizona State University (Bachelor's,1980)
  - University of Arkansas (Bachelor's,1991)
  - Boston University (Bachelor's,1983)
  - Carleton (1984)
  - University of Massachusetts Amherst (Bachelor's,1978)
  - Union College (Bachelor's,1998)
- Computer and Systems Engineering
  - Rensselaer Polytechnic Institute (Bachelor's,CoOp,1978)

- Electronic Systems Engineering
  - University of Regina (1995)
- Engineering Systems and Computing
  - University of Guelph (1994)
- Environmental Systems Engineering
  - Clemson University (Master's,1967)
  - Pennsylvania State University (Bachelor's,2000)
  - University of Regina (2000)
- Génie des Systèmes Électromécaniques [accents]
  - Universit de Quebec a Rimouski (1998)
- Geosystems Engineering and Hydrogeology
  - University of Texas at Austin (Bachelor's,CoOp,2000)
- Industrial and Systems Engineering
  - The University of Alabama in Huntsville (Bachelor's,CoOp,1974)
  - Auburn University (Bachelor's,CoOp,1967)
  - University of Florida (Bachelor's,CoOp,1936)
  - University of Michigan-Dearborn (Bachelor's,1975)
  - The Ohio State University (Bachelor's,1936)
  - Ohio University (Bachelor's,1968)
  - San José State University (Bachelor's,1963)
  - University of Southern California (Bachelor's,1957)
  - Virginia Polytechnic Institute and State University (Bachelor's,CoOp,1936)
  - Youngstown State University (Bachelor's,1988)
- Industrial Systems Engineering
  - University of Regina (1984)
- Manufacturing Systems Engineering

- Kansas State University (Bachelor's,1988)
- Kettering University (Bachelor's,CoOp,1990)
- University of St. Thomas (Master's,1991)

- Marine Engineering Systems
  - United States Merchant Marine Academy (Bachelor's,CoOp,1982)
- Marine Systems Engineering
  - Maine Maritime Academy (Bachelor's,CoOp,1994)
  - Texas A & M University at Galveston (Bachelor's,1993)
- Systems Analysis and Engineering
  - The George Washington University (Bachelor's,1984)
- Systems and Control Engineering
  - Case Western Reserve University (Bachelor's,CoOp,1971)
- Systems Design Engineering
  - University of Waterloo (1974)
- Systems Engineering
  - Air Force Institute of Technology (Advanced Master's,1975)
  - University of Arizona (Bachelor's,1981)
  - George Mason University (Bachelor's,1995)
  - Oakland University (Bachelor's,1979)
  - United States Military Academy (Bachelor's,1997)
  - United States Naval Academy (Bachelor's,1970)
  - University of Virginia (Bachelor's,1981)
- Systems Science and Engineering
  - University of Pennsylvania (Bachelor's,1982)
  - Washington University (Bachelor's,CoOp,1977)

- Urban Systems Engineering
  - George Mason University (Bachelor's,1995)

Appendix F

Extracts from *Planning for the New Workshop Series*

This appendix quotes verbatim from *Planning for the New Workshop Series.* [213] The author acknowledges that the report is based largely on person opinion and on, presumably, unstructured discussions with faculty members in Systems Design Engineering. From discussions with a number of faculty members, over the last 10 years this document has not received wide distribution, nor have its recommendations been implemented.

> "This report examines possible new directions for the workshop series. There are several goals motivating the suggested changes. These are providing students with:
>
> - a better sense of 'just what is systems design engineering?'
> - a better appreciation for the relevance of their courses,
> - a better understanding of relationships between theory and practice,
> - a more effective design experience, and
> - a better attitude towards group design work.
>
> In exploring these goals the report presents the following conclusions:
>
> - the 1A curriculum needs to better prepare students for their years in systems design,
> - the department should add course content to the workshop courses,

- students need to complete several iterations of the design process for each workshop, and
- students should not work in large design groups until they are comfortable with design as individuals.

These conclusions lead to the following recommendations:

- the department should add laboratories to the first year courses and use the book *How Things Work* to discuss the application of theory to practice,
- SYDE 161 should include engineering history as part of its curriculum,
- a smaller project aimed at individuals should replace the major group project in 1A,
- students should work in small groups of 3 or less in 3A, and larger groups in each succeeding term resulting in productive design teams in fourth year,
- there should be lectures on design methodology and design history in the workshop series, with accompanying texts for the courses,
- students should implement their final solutions for all their workshops, and
- the department should author a paper, describing the history of the workshops and any proposed changes, for publication in *Engineering Education* or a similar journal, and for distribution to new faculty and workshop supervisors." [213]

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