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# Constructing Teaching Practices Around Novel Technologies: A Case Study of Three Universities

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ABSTRACT

Constructing Teaching Practices Around Novel Technologies:

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This dissertation presents three cases of professors implementing a new technology – the CyclePad articulate virtual laboratory – in their classrooms. The professors' teaching practice is examined based on a model of change derived from Cuban's (1999) study of departmental change at Stanford. The analysis compares the depth of pedagogical change with the breadth of curricular change. Pedagogical change runs from minor changes to major or radical transformations of teaching in a domain. Breadth of change is the degree to which the changes and modifications are made to the curriculum-- from narrow (alterations to one curricular unit) to broad (restructuring an entire course or sequence of courses). Additionally, this study examines contextual effects across three different types of institutions: a private research university, a military academy and a public state university. To situate the cases in the larger context of engineering education, a survey of 107 engineering professors was conducted.

The curriculum that professors developed for CyclePad arose from their pedagogical content knowledge -- knowledge of the subject area,

knowledge of curricular and instructional practices and an understanding of their students. Drawing on this, professors created problems and activities that were tailored to the specific needs of their classrooms. Yet, this was often shaped by departmental demands to standardize curricula in multiple-section courses. The degree to which technology becomes a part of curriculum depends on several factors such as the time and effort required to make significant pedagogical improvement and the degree to which the other community members support radical curricula or pedagogical reform. As found in the surveys, schools and departments are more likely to encourage the use of technology than to offer release time from teaching to develop new curriculum.

In examining instructors' teaching practices, it seems that the role of context has been under-emphasized in models of pedagogical content knowledge and in studies of engineering education. This dissertation posits a model for engineering education context that includes: subject matter, students, colleges, university, employers, professional contexts, and institutional environment. These nested environments are the spaces which professors negotiate in defining classroom practices.

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# CHAPTER 1

# INTRODUCTION

> The process of engineering education should change to use more effective pedagogical approaches and to engage students more effectively in the educational enterprise. Emerging technologies, including multi-media, computer-based simulation and computer-aided engineering, can be important components in the educational process . . . " (NSF Workshop on Engineering Education, 1995, p. 12)

## Introduction

Many studies of higher education highlight the need to embrace new pedagogical styles (Boyer Commission, 1995; National Research Council, 1996; National Science Foundation, 1996). As shown in the opening quotation, some groups and organizations see new technologies as a means of revitalizing traditional approaches to higher education and therefore push colleges and universities to adopt them. While some of these programs offer the promise of universities to adopt them. While some of these programs offer the promise of improved teaching and learning, previous research has found technology, time after time, to be a failure in creating meaningful change in educational practices (Cohen, 1988; Cuban, 1996).

Few studies in higher education have examined how universities and professors respond to innovations in technology or policy. Evans (1970) took a psychological approach to studying resistance to the innovation of instructional television at universities. Almost forty years later, we can see that IT failed to take hold. More recently, Larry Cuban's work has shown that educational institutions, both K-12 and college-level, appear to be resistant to change and that most interventions become passing fancies. Much of Cuban's work has taken a historic approach to analyze attempts at reform in education. In Cuban's (1999) latest book, How scholars trumped teachers: Change without reform in university curriculum, teaching, and research, 1890-1990, he presents a model for understanding how educational policies aimed at creating meaningful change can end up having little impact on the university.

If the current buzzwords in technology --"distance education" "simulations" and "virtual reality" -- are to be more than educational fads, Cuban argues that we need a better understanding of the complex environment where these technologies will be used. To do this, we need to build bridges between the technology developers, educators and policy makers in order to understand how to use technology as part of educational reforms (Cuban, 1996; Menges & Austin, in press). For Cuban, this means moving our focus from blaming failures on those who implement the technology to developing a greater understanding of the context in which teachers work. He writes:

> Suppose we reframe the problem and shift the center of gravity from blaming teachers to understanding how their workplace, their efforts to cope with conflicting goals and their notions of efficiency make greater demands on their time. For techno-reformers to generate genuine solutions, they will need to give far more attention to describing the places where computer-assisted learning has worked – to conditions under which a hardy band of

> pioneering teachers and entire schools have learned to use information technologies imaginatively. (p. 3)

As mentioned earlier, Cuban (1999) set forth to understand the environment of university education in his study of Stanford. While his work examines policies and their implementations at the departmental level, the work presented in this dissertation examines technology implementation at the classroom level. My intent, like Cuban's, is to better understand the work environment of professors, how they negotiate their environment and how their work practices vary from their desired practice.

## Problem Statement

In higher education, the college lecture is the least changed aspect of teaching, having been the dominant pedagogical style for over a century (Cohen, 1988; Cuban, 1999). While some professors have begun to embrace other pedagogical techniques, little attention has been paid to examining actual classroom practices beyond self-reports of teachers (Bourne, et. al., 1995). Some studies of higher education teaching take an evaluative approach (e.g., those based on student surveys) or a prescriptive perspective (e.g., Chickering's (1991) Seven Habits of Effective teachers). Ehrmann (1999), of the Flashlight technology evaluation project, claims, "few institutions are asking whether technology fosters change in teaching because those practices are seen as province of individuals and isolated courses..." (p. 28).

The view that professors have dominion over their classrooms has perhaps created reluctance on the part of researchers to examine teaching practices. This may be further complicated by a general avoidance by the academe to reflect inward. Cuban writes about the political reasons for professors' avoidance of this topic:

> Consider the organizational conflict that would arise from mandating that professors use more technology in their instruction or from elevating teaching to equal status as a criterion for gaining tenure. Such open conflict threatens organizational stability. Hence, faculties search for ways of avoiding destructive intramural battles. One way to do that is to divorce content from pedagogy. The

> dominant belief is that *what* is taught is far more important than *how* it is taught. (Cuban, 1999, p. 88)

However, recently, some researchers (e.g., Irby, Hillocks, and Lenze) have begun to look more closely at university teaching by reuniting content with pedagogy. In doing so, they are more interested in how a subject matter is taught than in arguing about what is taught and what should be taught. Lee Shulman, who leads this effort at the Carnegie Foundation for the Advancement of Teaching, has launched programs to help develop discipline-specific understandings of university teaching practices. He writes:

> We intend to set out a long-term plan for systematic studies of the pedagogies of the professions, both for their own sakes and for the light that studying the variety of ways in which professionals teach and learn might cast on undergraduate liberal education in general. From public service to internships, from case methods to collaborative group work, professional education actively confronts

many of the most contemporary challenges of creating "pedagogies of engagement." [1]

Thus, while the work presented in this dissertation focuses on engineering education, I believe that the ideas presented are of relevance to higher education as a whole. While much research has focused on medical education and its use of problem-based learning, engineering education is also undergoing a similar process of change towards more engaging pedagogies. Unfortunately, fewer educational researchers work in the field of engineering education. This dissertation will add to the growing body of knowledge about college-level teaching, as well as, explore a field – engineering – where there is only a small corpus of educational research.

**Purpose of Study**

The purpose of this study is to examine how instructors respond to new educational innovations. Specifically, I am interested in how professors

[1] From: http://www.carnegiefoundation.org/message.html

negotiate teaching with a new technology within the context of their university environment. What would they like to do, ideally, with the technology? Are they able to achieve this? In negotiating their environment, what compromises do they make in their teaching practice?

This study takes a longitudinal and a cross-institutional perspective to develop case studies of three professors integrating a new software program into their classes. By following professors for several years, I am able to see how their teaching practice evolved and what progress, if any, the professors made towards their models of ideal technology usage. Furthermore, the cross-institutional perspective allows me to compare their efforts in several different university contexts.

## Framework

The framework guiding this research is based Cuban's (1999) framework of organizational and institutional change. As described below, I have modified Cuban's model to look specifically at classroom-level teaching and examine teacher's ideal implementation of technology versus their actual teaching practice.

Cuban has spent many years examining the stability of educational practices in the wake of new technologies and reform initiatives (e.g., Cuban, (1992), (1996), (1999)). In his most recent work, (Cuban, 1999), he examined the history of reforms in two Stanford University departments - medicine and history. In doing so, he developed an analytic framework that would account for the stability he found in educational practices over time as well as the areas in he found progress had been made.

Part of the challenge in developing this framework, for Cuban, was to explain how small reforms sometimes led to fundamental and broad-based change while some large reform projects only had a modest impact in a small arena. Cuban developed a model with four dimensions: depth, breadth, level and time which, when examined together, he felt, could account for intended reforms of varying scope and the differences in the outcomes of their implementation. Using this framework, he compared enacted reforms with their intended agenda. This model is described in more detail below.

"Depth" and "breadth" measure the magnitude of change. Depth is the "degree to which designers of innovation seek to make minor, modest, major changes or transformations of key structures, cultures, and processes ..." (Cuban, 1999, p. 62). The degree of the depth runs from incremental to fundamental. Incremental change assumes "that the basic structures are sound but need improving to remove defects that hinder effectiveness and efficiency (Cuban, 1999, p. 63)." Fundamental changes "aim to alter drastically the core beliefs, behaviors and structures of the university (Cuban, 1999, p. 64)." Breadth of change runs from "narrow," change in one or two structures or processes, to "broad," change in a systemic fashion. Figure 1 shows the interaction between depth and breadth and the resulting four types of reforms.

Figure 1. Cuban's model of change

DEPTH

*INCREMENTAL*

BREADTH

*NARROW*

| | |
|---|---|
| *Narrow, Incremental*<br>**1** | *Broad, Incremental*<br>**2** |
| *Narrow, Fundamental*<br>**3** | *Broad, Fundamental*<br>**4** |

BREADTH

*BROAD*

DEPTH

*FUNDAMENTAL*

To illustrate the application of this framework, Cuban cites the example of City University of New York's (CUNY) change in admission policy in 1970 to open admissions. What began as a narrow, fundamental change (quadrant 3) years later resulted in broad changes (quadrant 4) to instruction and curriculum as professors and administrators tried to cope with the decline in academic quality of the students. In terms of Cuban's model, CUNY started in quadrant three and ended up in quadrant four.

As an example of a narrow, incremental change, Cuban cites the reduction in faculty teaching load from 5-6 courses to four courses in the 1960s (Cuban, 1999, p. 67). Incremental changes are intended to improve upon an existing system, rather than alter its fundamental premise. This example is narrow in its breadth (affecting only one organizational structure), incremental in its depth and therefore would be represented in quadrant 1. Standing in contract to this is the failed reform attempt of SUNY Buffalo to transform itself into the "Berkeley of the East" (Cuban, 1999, p. 66). A reform with a scope such as that, seeks to make fundamental changes across many of the universities operating procedures. Thus, Cuban classifies it as being of broad breadth and fundamental in depth (quadrant 4). If a university were only making curriculum changes this would be classified as broad change with an incremental depth (not changing the university fundamentally). Cuban places examples of Stanford's curriculum changes in 1920, 1956, 1968 and 1994 in quadrant 2(Cuban, 1999, p. 67).

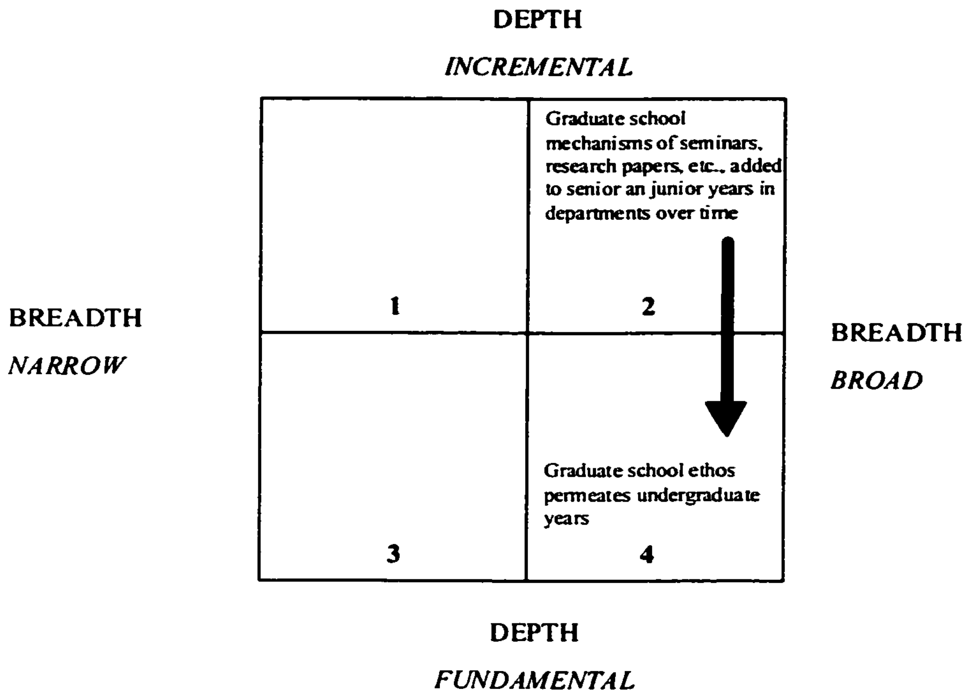
To look at the outcomes of proposed and adopted changes, such as in the CUNY example, Cuban adds elements of time and level. Level describes the locus of analysis in the educational organization. For example, it may be an individual professor, classroom, department or university. Cuban explains how each level of the organization would need to be accounted for:

> Breadth and depth of change can ... be applied to each level of authority and decision-making in a university, including the classroom. Each application of the matrix, say, to the professor's classroom and then to a department or school, would need to consider the interacting linkages to other levels in an institution where governance is so dispersed and the organization so bottom-heavy. (Cuban, 1999, p.68)

His book, however, focuses only at the departmental level. He provides no examples of how to apply this model to the classroom level.

The fourth component, time, is key to comparing the intended reform with the outcome. In one of Cuban's examples, he plots the diffusion of graduate school practices to undergraduate courses that occurred at universities over the 20th century (as shown in Figure 2). The arrow in the diagram indicates time and direction of change. Throughout the 1900's changes were made to the undergraduate curriculum, especially in the junior and senior years. Ideas from the graduate schools, such as "specialized colloquia, seminars, honors programs, reading periods, comprehensive exams and research projects" slowly became the norms for undergraduates too (Cuban, 1999, p. 73). These changes created a greater distinction between the liberal arts education and the more graduate school-research focus of undergraduate education at research universities. Later in the century, as Cuban notes, this topic became a source of debate as universities questioned the mission of preparing undergraduates for graduate school. The cumulative effect of these incremental changes was a fundamental change in undergraduate education, yet it is important to stress that in making the changes, the net result was not necessarily the intention of each individual change. This example illustrates how a large shift in education can be the result of years of incremental changes rather than a planned fundamental change.[2]

Figure 2. An example of incremental change becoming fundamental[3]

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[2] Cuban found examples of other shifts (such as reforms meant to produce fundamental changes in structures resulting in only incremental change) in his study of universities.

[3] Diagram from (Cuban, 1999) p. 75

For this dissertation, I use Cuban's notions of "depth" and "breadth" to examine how professor's implement technology at the classroom level. To examine this, I conceptualize breadth and depth in terms of curricular and pedagogical change. Breadth of change is the degree to which the changes and modifications are made to the curriculum-- from narrow (alterations to one curricular unit) to broad (restructuring an entire course or sequence of courses). Thus a one-week team-based project using technology would be a narrow curriculum change while the adoption of a new yearlong mathematics program would be a broad curricular change. However, as many researchers have noted, using new tools or materials does not necessitate pedagogical change. The second axis, depth, is the degree to which professors, as curriculum implementers and, often, designers, seek to make minor, modest, or major transformations in their teaching of a domain. For example, certain reforms are intended to change pedagogy (such as in project-based science where the teacher becomes a facilitator of groups) whereas back-to-basics movements seek to use traditional pedagogy with regimented curricular activities.

Figure 3 shows several examples of different types of curricular and instructional changes mapped out using this framework. The goal of progressive reformers is to move education towards the fourth quadrant - improving upon both curriculum and instruction. As found in this study, this was also the goal for engineering instructors.

Figure 3. Examples of classroom change

DEPTH

*INCREMENTAL*

BREADTH

*NARROW*

| | |
|---|---|
| Example<br>new technology used in one unit or part of a course<br>**1** | Example<br>new course curriculum using traditional pedagogy<br>**2** |
| Example<br>radical change in instruction in one unit or topic<br>**3** | Example<br>adoption of new pedagogy across entire course with re-structuring of curriculum<br>**4** |

BREADTH

*BROAD*

DEPTH

*FUNDAMENTAL*

## Pedagogical Content Knowledge

As the content for this research is the usage of a specific software program in the teaching of thermodynamics within Mechanical Engineering programs, the model I use for examining teaching, is one that embraces both content and pedagogy (Grossman, 1990; Grossman & Stodolsky, 1994; Shulman, 1986; Shulman, 1987). In Shulman and Grossman's models of teacher cognition, they have explored the notion that teachers develop domain-specific teaching strategies that link pedagogical practice with subject matter knowledge They argue that teachers and professors have a cache of general pedagogical techniques and a wealth of subject matter knowledge, they label knowledge, which merges and intertwines the two, as *pedagogical content knowledge* (PCK). I use the construct and components of PCK in my analyses of professors' teaching practices.

In Grossman's (1990) model, PCK comprises knowledge of the conceptions of purposes for teaching a subject matter, knowledge of students' understanding (e.g., misconceptions), curricular knowledge and knowledge of instructional strategies. Curricular knowledge includes knowledge of the curriculum of a course (e.g., available materials and rationale for their usage (Shulman, 1986)) and an understanding of how a course fits into larger educational structures (e.g., both horizontal and vertical integration within an academic field or major (Grossman, 1990)). Instructional strategies include the representations, analogies, illustrations, examples, explanations and demonstrations that are used to teach specific content to students (Grossman, 1990).

This model of domain-specific teaching is useful in examining technology implementation as programs, such as simulations, which bring new forms of representation of subject matter into the classroom. Thus, in a way, certain tools and materials can be seen as expanding an instructor's repertoire of instructional strategies in addition to their curricular knowledge. By viewing teaching through the lens of PCK, I can highlight how professors expect technology to enhance their teaching practice in ways that are specific to the subject matter.

**Teaching Context**

In addition to teaching being situated in disciplines, teaching practices are also situated in schools, universities and communities. In most research of teachers' PCK, discussion of teaching context has been minimal or absent. Shulman, in his introduction to Hillocks (1999) study of community college English-composition teachers, questions Hillocks' dismissal of context as a relevant component of teacher knowledge in his study (see Hillocks, 1999, p. 123). Shulman writes:

> If I am critical of any aspect of this book [Hillock's], it is a criticism that I level at most of my own work as well. Hillocks takes a decidedly psychological approach to the problem of teacher knowledge and teaching practice. He entertains the possibility that context plays a role in the shaping and sustaining of those beliefs and practices, and dismisses the hypothesis rather quickly. I think that in this matter, he and I have both erred. The work of Milbrey McLaughlin and Joan Talbert of Stanford has confirmed repeatedly

> that variations among secondary school departments in the teaching practices of their faculty members can be attributed significantly to context-driven differences in their beliefs about both their subjects and their students. ...It may well be that changing the context in which one teaches can have more influence on beliefs and practices than any individual interventions can hope to accomplish. (Hillocks, 1999, p. ix-x)

Ruscio, perhaps, provides us with an explanation for this oversight. He speculates, "Institutional differences operate more covertly than disciplinary differences...[they] remain in the shadows. A discipline is the first mark of identity a professor receives; institutional affiliation comes after the training, after the socialization."(Ruscio, 1987, p. 323) Perhaps, for this reason, studies of context-specific teaching practices have begun by looking at the realm of the subject-matter domain and are slower to see institutional context as an important factor.

This is not to imply that there have been no studies of institutional differences. Many studies employ the Carnegie Commission on Higher Education's (Boyer, 1994) classification scheme which groups post-secondary schools into ten categories[4] to do cross-institutional research. These studies have found, for example, differences in institution's educational goals (Smart & Ethington, 1995), in how much time faculty spend teaching (NSF study as cited in (Ruscio, 1987) in interactions with students (Astin & Astin, 1992) and in how faculty learn about teaching (Blackburn & Lawrence, 1995). Faculty at institutions that place a greater emphasis on teaching, such as at community colleges, find it harder to maintain ties with the research community (Ruscio, 1987). Other institutional differences have been identified, such as size, location, age, academic standards, etc. (Clark, 1987; Ruscio, 1987) (Austin, 1992). What these studies tend to share is a more behaviorist approach to

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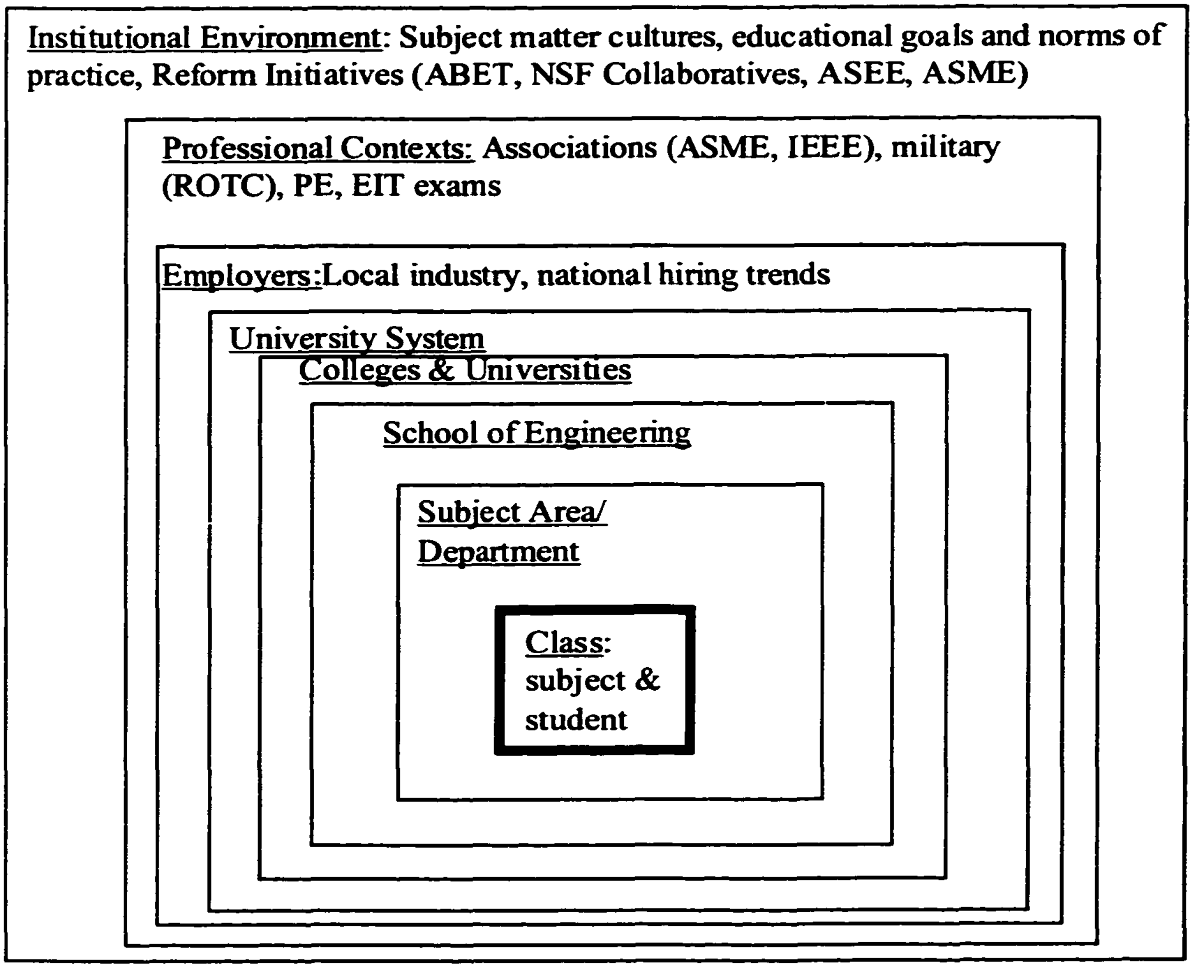
[4] The categories are: Research I and II; Doctorate- Granting I and II; Master's (Comprehensive) Universities and Colleges I and II; Baccalaureate (Liberal Arts) Colleges I and II; Associate of Arts Colleges; and Professional Schools and Other Specialized Institutions. (Boyer, 1990)

studying teaching. Little is known about the process by which institutional differences shape pedagogical practices.

As Shulman mentioned above, Talbert and McLaughlin's work in secondary schools has shown that teachers' beliefs about students and subject matter differ due to their perception of their work context (Talbert & McLaughlin, 1993). Their research takes a more complex view of teaching by examining not one environmental variable, as is often the case in higher education research, but multiple contexts. Research that only considers one context, Talbert and McLaughlin argue, can lead to misrepresenting the effects of that variable. By examining the complex interactions between the context of teachers' work and their practice, they argue, one can better understand the conditional nature of any single context upon teachers. In their research on high school teaching, they define context as embracing a wide range of factors: classroom (subject and students), subject area/department, school organization, school sector/system, parent community/social class culture, higher education institutions, local professional context, and institutional environment. In their view, it is these multiple contexts, seen as nested within each other, that teachers negotiate.

Borrowing from Talbert and McLaughlin, I describe context as complex and multi-layered in my examination of its role in instructors' PCK. It is not a backdrop or precursor to teaching but integral in how teaching practices are constructed by professors. I define the university context as consisting of students, classroom, departments, schools or colleges within the university, accreditation agencies, employers, and local industry (see Figure 4). This definition is shaped, in part, by the scope of this dissertation, which focuses solely on engineering instruction. Thus, for example, local industry is particularly important since it often tightly connected with engineering schools through internships, support for new strands in curriculum (such as telecommunications or semiconductor manufacturing) and through hiring of graduates. Also, agencies such as the Accreditation Board for Engineering and Technology (ABET) are essential as they set the minimum standards for engineering curricula and faculty. This dissertation contributes to the literature by presenting this model for examining engineering education context.

Figure 4: Contexts of Engineering Teaching



In looking across teaching practices at several institutions, this framework of nested contexts provides an additional tool for analyzing professors' negotiation of their environments. For example, while they may have wanted to implement technology in a certain way, they may also feel that they are constrained by certain factors in their environment. By viewing the university context as a complex work place with competing interests, one can better understand how and why professors make the instructional choices they do.

## Research Context

This study is part of the Articulate Virtual Laboratories for Science and Engineering Education grant and is funded by the National Science Foundation's (NSF) Applications of Advanced Technology Program. This dissertation focuses on implementation one of the software programs -- CyclePad - which was developed for teaching university level thermodynamics. [5]

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[5] CyclePad was also used for AI research purposes that will not be discussed in this dissertation. See Forbus (1997, 1998, 1999), Forbus & Whalley (1994) Forbus et al., 1998).

CyclePad is an articulate virtual laboratory (AVL) in which students can build, design and analyze thermodynamic cycles. From an educational perspective, CyclePad was built for two purposes (1) to help improve student learning of thermodynamics and (2) to allow students to engage in design tasks that they were otherwise unable to perform. One of the central features of CyclePad was scaffolding and coaching to help students build and analyze their designs. Central to this project was the belief that design activities are key to motivating students and improving learning. Professor Forbus explained this position:

> Today's homework are cookbook exercises, with single right answers. Easy to grade, easy to do (in terms of amount of math slogging). Not very motivating. Bringing the work students do closer to the design context should be more motivating, provide for more open-ended questions, and help them see where and how thermodynamics concepts matter. That's what we're really after, not to turn them immediately into consulting engineers. (From e-mail to CyclePad research team on 4/9/99)

CyclePad has been used by engineering faculty for demonstrating concepts and applied principles, for creating student laboratory projects, for student projects and term papers, for students to do and check homework problems and for personal research projects. In this study, several of these types of implementation will be discussed.

## Study Overview

This study focuses on the usage of CyclePad by instructors at three different institutions; one institutions that was affiliated with the NSF grant -- Northwestern University (NWU) - a second institution supported by a grant from the Cognitive Science Division of the Office of Naval Research -- the United States Naval Academy (USNA) -- and a third institution (University of Arkansas at Little Rock (UALR)). This dissertation begins, however, with a background survey of a larger population of professors who teach thermodynamics (Chapter 2). The survey is meant to provide an introduction to how professors think about teaching this domain and how they might imagine teaching in the future. This broad examination of engineering education practices is followed by in depth case studies.

In chapter three, I describe the case study methodology used for studying the teaching practice of professors who are using a new technology in their classrooms. This is followed by the cases of instructors who represent three different educational institutions; a private research university (chapter four), a military college (chapter five) and a large state school (chapter six). For each case, I discuss the instructors' enactment of curricula incorporating CyclePad and contrast it with their ideal usage of CyclePad. I conclude, in chapter seven, with a discussion of policy, theory and technology design implications.

The cases are similar in that all three professors share the goal of creating a revised curriculum embodying a progressive pedagogy (design-based learning). While there are similarities in their ideal vision of thermodynamics education, their ability to effect change in the classroom varies from case to case (and within the cases – from course to course). The case of Professor P. (UALR) is an example of narrow curricular usage of CyclePad with a goal of integrating it broadly into the curriculum. While at USNA, Professor R. has a broad curricular CyclePad implementation -- yet employing in one course a traditional pedagogical approach and progressive pedagogical practices in another course. At NWU, the implementations of CyclePad were quite different; one reached broad curricular integration yet with limited pedagogical impact. In the other course, CyclePad was implemented with a fundamentally different pedagogy, however, limited to one a small slice of the course. These cases provide three perspectives on the efforts of professors to create innovative curriculum using progressive pedagogical practices in engineering education.

# CHAPTER 2

# TEACHING SURVEY

In this chapter, I present the results of a survey of thermodynamics professors conducted during 1999. This survey was driven by a need to understand the status quo of thermodynamics teaching and the viewpoints that faculty hold on potential changes to curriculum and instruction. The National Science Foundation (NSF) has conducted several comprehensive studies in the science and engineering fields, however, the studies mainly focus on demographic and economic data, and less so on teaching practices. Furthermore, these studies treat engineering as one domain and do not look at the departmental/subject matter level. For example, the NSF report "Characteristics of Doctoral Scientists and Engineers in the United States" (National Science Foundation, 1999) provides demographic information for the number of doctoral engineers in academia, however, this data is not broken down by either school type or engineering discipline. Other reports such as "Scientists, Engineers, and Technicians in Non-manufacturing

Industries" do not include the academic jobs (National Science Foundation, 1996). In the National Science Board's "Science & Engineering Indicators - 1998" there is detailed information about science and engineering students and institutions and little about faculty (National Science Board, 1998). Therefore, I created a domain-specific teaching survey to compare teaching of thermodynamics across different programs (engineering technology and engineering science) and universities to better understand the similarities and differences across contexts as well as the general nature of teaching thermodynamics.

## Introduction

There are few cross-institutional studies of higher education that examine domain specific teaching practices. Most compare teaching practices across disciplines (e.g., science teaching (Astin & Astin, 1992)), or focus on general pedagogical practices (e.g., (Blackburn & Lawrence, 1995; Boyer, 1990)). I chose to survey professors who, like those selected for the case studies, had taught or currently teach thermodynamics. I selected a sample of thermodynamics professors who came from a wide range of universities so that I could compare responses across institutional type and engineering programs. The aim of the study was to answer the questions: What is the nature of thermodynamics professors' teaching practices (the range of their interests, the degree of departmental support for improving teaching, their pedagogical preferences)? How would professors ideally teach thermodynamics? What do professors see as the challenges for students to learn thermodynamics? How do these teaching practices and viewpoints vary across institutions?

## Methodology

After a review of the literature I found few scales that measure these domains of interest, so I developed a twenty-three-question survey. This survey consisted of a combination of fourteen short-answer and open-ended questions and nine structured questions (multiple-choice, checklist and ratings). Questions covered the following topics (see survey in Appendix B):

- Demographics (where they teach, type of institution, teaching background, tenure status, industry experience)
- Views on textbook problems (benefits, drawbacks, what students find difficult and what they learn)
- Teaching thermodynamics (names of thermodynamics courses taught, perceived challenges, learning goals, and teaching styles)
- Available resources (laboratory equipment, departmental support)
- Views of students' skills and motivation and how difficult students find specific concepts
- Views on teaching under ideal conditions (i.e., with unlimited time and resources)

To reach professors who teach thermodynamics I took three approaches. First, I developed a web-based survey that was located on our web site. While users were waiting to download CyclePad, they saw a request for professors to follow the link to the survey. Second, to reach professors who might not be visiting our web site, I searched the Internet by examining university web sites of all ABET accredited engineering and engineering technology programs. From there, I obtained e-mail addresses for instructors who were listed as teaching thermodynamics (on department homepages or by using course catalogs). When the web-based faculty listings did not list faculty's courses, I selected professors whose research seemed to be in the area of thermodynamics (such as heat transfer) who might possibly be assigned to teach the thermodynamics courses. Overall, I was more successful at finding e-mail addresses for mechanical engineering professors at engineering programs than for engineering technology. I found that engineering technology programs were much less likely to have comprehensive web sites - often there was no faculty listing at all. I gathered the e-mail addresses into a mailing list and sent requests to the professors to complete the on-line survey. Last, I posted announcements to mechanical engineering news groups and the engineering technology newsgroup asking professors who taught thermodynamics to complete the survey. In all, the survey was sent to 903 professors representing 249 schools (see school list section II of Appendix B).

After users completed and "submitted" the survey electronically, the data was automatically stored in a text file. The quantitative data was imported into Microsoft Excel and SPSS where it was analyzed. Qualitative data from open-ended questions was hand-coded, categorized and put into frequency tables.

One hundred and seven professors responded to the survey during a five-month period[6]. This represented a response rate of 12%. There are several explanations for the low response rate. First, not all e-mail requests reached their target audience[7]. Second, in selecting faculty for the mailing, whenever possible, I had tried to confirm that they taught thermodynamics either through a listing on their personal home page or by consulting the university's course catalog. However, many professors did not list teaching activities (they tended to list their research programs) and many schools do not yet have on-line catalogs (or, if they do, the catalogs list courses but not instructional staff.)

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[6] A second request to complete the survey was sent after one month had passed.
[7] Fifty-two of the surveys were returned as "unknown" by various mail servers.

For any one of these reasons, faculty included on the original mailing list may not have taught thermodynamics and elected not to return a survey. Although the response rate is low, final sample of 107 is likely one of the most extensive surveys of this population regarding teaching practice. This sample helps me situate the case studies in a larger context of engineering education.

**Who are the professors?**

The professors (n=107) were queried as to the number of years teaching, teaching thermodynamics and working in industry (see Table 1). The majority of respondents had over 10 years teaching experience (71%) and over 10 years experience teaching thermodynamics (59%). Two-thirds of respondents were tenured, one quarter was not tenured and for the remaining tenure-status was not applicable. New faculty members were not well represented in this sample. Seventy-five percent of the professors had experience working in industry.

Table 1: Work experience

| Number of Years | Teaching | Teaching Thermodynamics | Working in Industry |
|---|---|---|---|
| 0 | - | - | 25% |
| 1-5 | 18% | 25% | 35% |
| 6-10 | 10% | 15% | 20% |
| 11-15 | 21% | 17% | 8% |
| 15 or more | 50% | 42% | 12% |

While the sample appears skewed towards older professors, this is, in fact, consistent with the demographics of engineering and science professors. Due to a surge in hiring during the growth of the 1960s, followed by a slower rate of hiring in subsequent years, the average age of engineering and science faculty in 1995 was greater than 46. In 1995, 10.9% of faculty were under 35 years old, 32.8% were 36-45, 35.7% were 46-55, 17.8% were 56-65 and only 2.8% were over 65 (National Science Board, 1998). While this data cannot be directly compared with the data from this dissertation survey, as the latter asked for number of years teaching not age, it suggests that the general population of engineering professors is older and thus more likely to have been teaching for a greater period of time. Thus, this population appears to be representative of the larger population in terms of teaching experience.

<u>Where do they teach?</u>

Ninety-seven universities are represented in the sample, the majority of which are research and doctoral granting institutions (see Table 2). This is consistent with other demographic data. In 1995, the National Science Board (1998) found that research universities employ 41% of doctoral scientists and engineers (based on Carnegie Classifications). The remaining 59% were employed at other institutions. Similarly, in this study 43% of professors worked at research I and II universities and the remaining 57% at other institutions (see Table 2). This indicates that the sample is drawn from different schools in proportion to the overall representation of engineering faculty at those institutional types.

Table 2: Carnegie classification of schools

| Carnegie Classification | Percentage of U.S. respondents |
|---|---|
| Research Universities I and II | 43% |
| Doctoral Universities I and II | 24% |
| Masters (Comprehensive) Universities and Colleges I and II | 20% |
| Baccalaureate Colleges | 4% |
| Associates of Arts Colleges | 4% |
| Specialized institutions (military and engineering) | 4% |
| *Foreign (no classification)* [8] | N/A |

The Professors are located in both the U.S. (87%) and abroad.[9] Eighty-seven of the professors are in engineering programs and the remaining 20 in engineering technology. Seventy percent of the respondents came from mechanical engineering departments. The remaining 30% represent departments such as chemical engineering, energy, engineering technology, industrial and engineering technology, thermal engineering and physics.

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[8] The fourteen foreign schools are not classified and thus not included in this table.

[9] There were 14 foreign professors. One from each of the following countries unless otherwise indicated: Mexico(2), Canada, United Kingdom, New Zealand, Spain (2), Norway, Netherlands, Tunisia, Romania, Chile, Ukraine, and Poland.

The analyses presented below focus on the sample as a whole, or on the difference between engineering and engineering technology programs[10]. The statistical methods employed took into consideration the differences between the sample sizes.[11]

## Teaching Practices

In this section, I was interested in addressing several questions about engineering faculty's teaching practice: What is the primary focus of their energy - research or teaching? What is the primary pedagogical style they employ? How much support do they received from their school or department for improving their teaching practice, curricular materials or usage of technology? What are their opinions of conventional problem solving methodologies used in thermodynamics? With unlimited funds and resources, how would they *ideally* teach? The objective of this line of questioning was to

[10] The data was analyzed by Carnegie classification to compare research universities with non-research schools. Significant differences were found for only one measure (interest in research versus teaching). Thus this data is not reported.

paint a picture of the current state of thermodynamics teaching and the areas for potential change in the future. As described below, in several of these areas (research interests, departmental support) there were significant differences between engineering sciences and engineering technology professors.

## Interest in research versus teaching

In Scholarship Reconsidered (Boyer, 1990), the Carnegie Commission found that professors at doctoral granting universities (which includes research institutions) were significantly less inclined towards teaching than those at other types of colleges. Similarly, in this study, engineering science professors were less likely to be interested in teaching relative to research than engineering technology professors (means 3.14 and 3.85 respectively, $F=5.78$, $p<.02$) (see Figure 5). In looking at the types of institutions where each group works, these results reflect the findings of the Carnegie report. The

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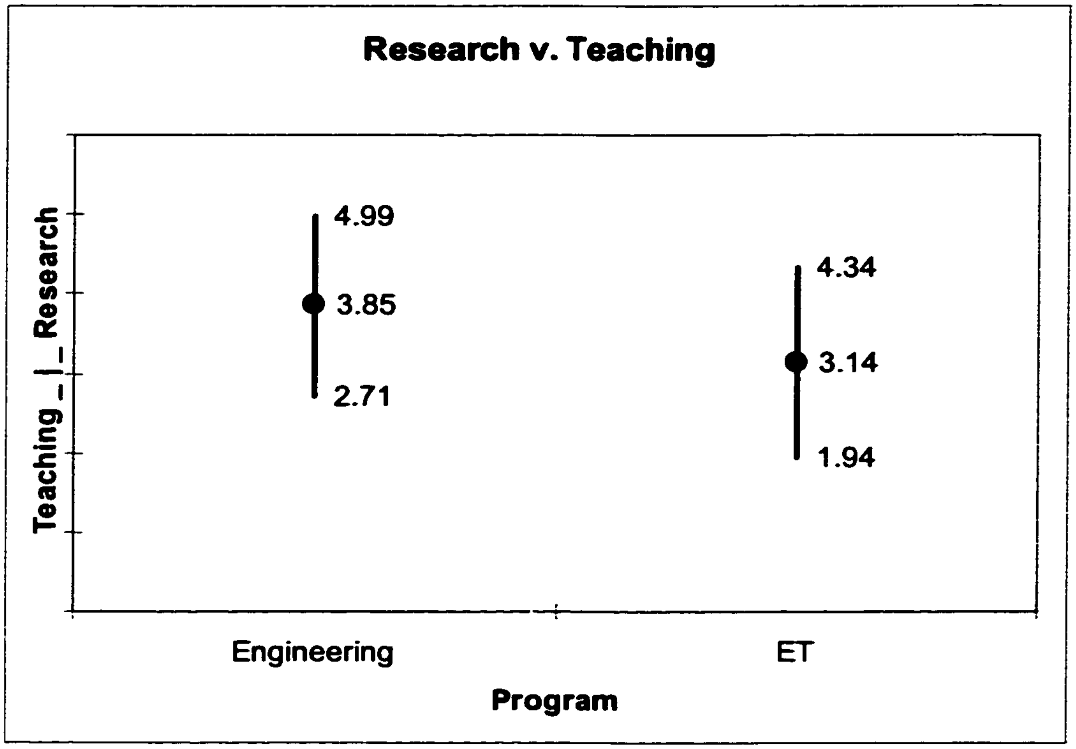
[11] Analyses were performed using SPSS (version 8.0). Analyses of mean differences between engineering programs were performed using the method of analysis of variance.

engineering science professors were more likely to work at research universities than the engineering technology professors (see Table 2).

Figure 5: Interest in research or teaching by program type



While this analysis looked at an individual's preference for research or teaching, the following analysis looked at the department's role in promoting and improving teaching practices.

**School/Departmental Support**

In this section, I wanted to look at differences between institutions in level of departmental support for improving teaching. From my contact with professors at different types of institutions, I had seen variation in the degree to which departments play a role in promoting excellence in teaching. For the analyses, a measure of school/departmental support for teaching was created that combined four individual survey items: departmental feedback on teaching to professors, discussion of course evaluations with professors, value of teaching as part of the tenure criteria and rewarding of good teaching (Cronbach's alpha = 0.69)[12]. Significant differences were found between professors in ET programs and engineering sciences professors perceptions of departmental focus on quality of teaching as shown in Table 3. Although the average professor in both types of programs rate their departments more positively than negatively in their support for teaching (greater than 3 on a five-point scale), the professors in ET programs rated their departments more positively compared to professors in engineering programs [3.76 (0.84) to 3.16 (0.99), F=6.42].

In analyzing the individual items, there is a trend for ET professors to rate all four measures higher than engineering sciences professors, with significant differences in three areas: ET departments are more likely to reward good teaching, provide feedback to instructors on their performance on course evaluations and give constructive criticism.

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[12] Items were combined based on conceptual rather than empirical considerations.

Table 3: Professors ratings of their departments' focus on teaching

| Construct and Items | ET | Engineering | |
|---|---|---|---|
| | mean (standard deviation) | mean (standard deviation) | F |
| **Departmental focus on quality of teaching** | 3.76 (0.84) | 3.16 (0.99) | 6.42* |
| *Individual Items* | | | |
| Teaching is important in tenure decisions | 3.90 (1.33) | 3.68 (1.19) | 0.42 |
| School/department discusses course evaluations with professors | 3.95 (1.21) | 3.15 (1.39) | 4.94* |
| Good teaching is rewarded by the department | 3.75 (1.33) | 3.14 (0.85) | 3.79* |
| School/department offers constructive feedback to help improve teaching | 3.45 (1.30) | 2.62 (1.50) | 6.30** |

Scale: 1 (unlikely) to 5 (likely)
*p<=.05, **p<=.01

In a second measure, analyses of departmental support for teaching reforms, there were no significant differences in ratings between the ET and engineering sciences professors (Cronbach's alpha = .73) (see Table 4). For this measure, four individual survey items were combined: the degree of encouragement for trying new computer technologies for teaching, the availability of incentives or technical assistance for using technology in the classroom, and the possibility of release time from teaching or summer funding to work on curriculum development.[13] While the professors mean ratings for individual items were very close between the two groups, it is interesting to note the larger gap on the measure of funding. The ET professors were less positive about the possibility of receiving summer funding from their school. This would also be consistent with the types of schools that they are more likely to teach at. In general, professors at large research universities have more access to funding in general than do professors at smaller teaching institutions[14]. This data supports the studies that cite the need to strengthen and improve the faculty reward system to help faculty balance the demands on research, teaching, and curriculum development. (Dowell, Baum, & McTague, 1994; National Science Foundation, 1996).

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[13] These items were also combined and analyzed as two measures: a department's support for technology usage and a department's support for curriculum development. A moderate correlation of 0.5 was found between the two measures. No significant differences were found between the two populations on these two measures.

[14] In 1995, the top 200 academic institutions accounted for 94% of research and development expenditures and the top 100 institutions accounted for 78% (National Science Board, 1998, p. 5-10).

Table 4: Professors views on departmental support for curricular change

| Construct and Items | ET | Engineering | |
|---|---|---|---|
| | mean (standard deviation) | mean (standard deviation) | F |
| **Departmental support for curriculum reform** | 2.92 (1.00) | 2.97 (0.87) | 0.05 |
| *Individual items* | | | |
| Encouragement for trying new computer technologies for teaching | 4.30 (0.80) | 4.06 (1.05) | 0.93 |
| Technical assistance for using technology in the classroom | 3.25 (1.33) | 3.20 (1.35) | 0.46 |
| Incentives to use technology in teaching | 2.8 (1.40) | 2.99 (1.28) | 0.33 |
| Option of release time from teaching for curriculum development | 2.20 (1.30) | 2.34 (1.34) | 0.19 |
| Availability of summer funding for curriculum development | 2.05 (1.44) | 2.42 (1.50) | 0.11 |

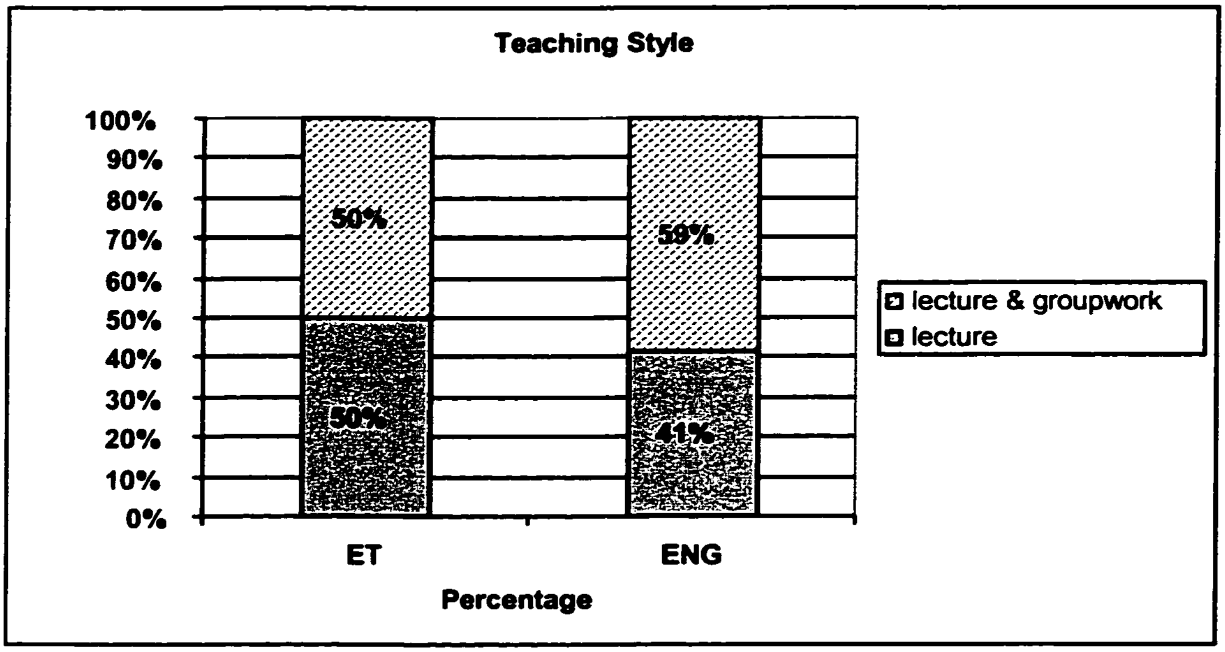
Scale: 1(low) to 5 (high)
*p<=.05, **p<=.01

The overall implications are that departments are more likely to encourage the usage of technology, but less likely to provide tangible supports for assisting in implementation. In the next section, I move from the departmental/school level, to looking at practice within the classroom.

## Teaching Style

As found in other studies of engineering professors (Bourne et al., 1995), lectures, or a combination of lectures with other styles, was by far the most prevalent form of instruction. Between 40-50% of the professors in both programs use forms of group work such as team problem solving, group projects and collaborative learning (see Figure 6). There was little difference between the two programs. This is most likely due to the fact that professors are trained in Ph.D. programs at research and doctoral universities, thus, regardless of where they end up finding academic positions, the types of teaching they have been exposed to is the same.

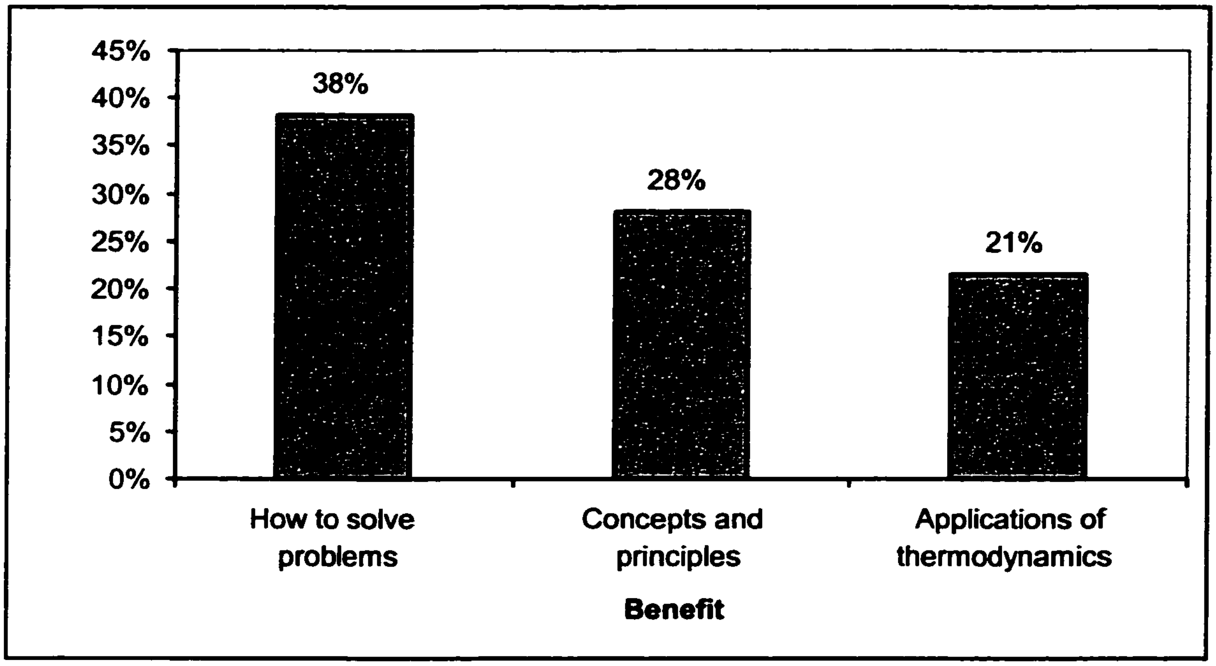
Figure 6: Professors' teaching style by program




## Thermodynamics Problem Solving

Along with the lecture, the traditional means of thermodynamics teaching has been the usage of paper-and-pencil problem solving. These problems (similar to those employed in physics) are organized in textbooks to correspond to specific chapter topics and simplified so that students can work them out with minimal technological support (today's students would be expected to use a calculator). Using a series of open-ended questions, professors were asked to report about what they perceived to be the benefits and drawbacks of students solving thermodynamic problems by hand (i.e., without equation solving software or other tools except for calculators). Figure 7 shows the top three benefits that professors identified. The most common response (38%) was that students learned better the methodology of problem solving. Secondly, professors (28%) claimed that students learned concepts and principles through solving problems by hand. Thirdly, professors (21%) felt that students learned better how to apply thermodynamics to solve engineering problems.

Figure 7: Top three benefits of conventional problem solving




Professors felt that by solving these problems students "reinforced" their thermodynamics knowledge. In particular, some believed that the slow pace of solving problems by hand allowed for greater reflection on the students' part. They also felt that this type of problems solving allowed students to get an intuitive sense of the magnitudes of variables. Professors wrote:

Drawing diagrams and writing out the formula helps reinforce the basic facts and theories. (Professor ID #20)

[Solving problems by hand] gives students time to think about analysis. Students see values of numbers to help them understand size of numbers. (Professor ID #40)

[Students are] learning and developing problem-solving skills, and gaining familiarity with overall magnitudes of common devices. (Professor ID #31)

[Solving problems by hand requires] conscious thinking about equation, units and quantities entered, and making a judgment on correctness of answer. (Professor ID #57)

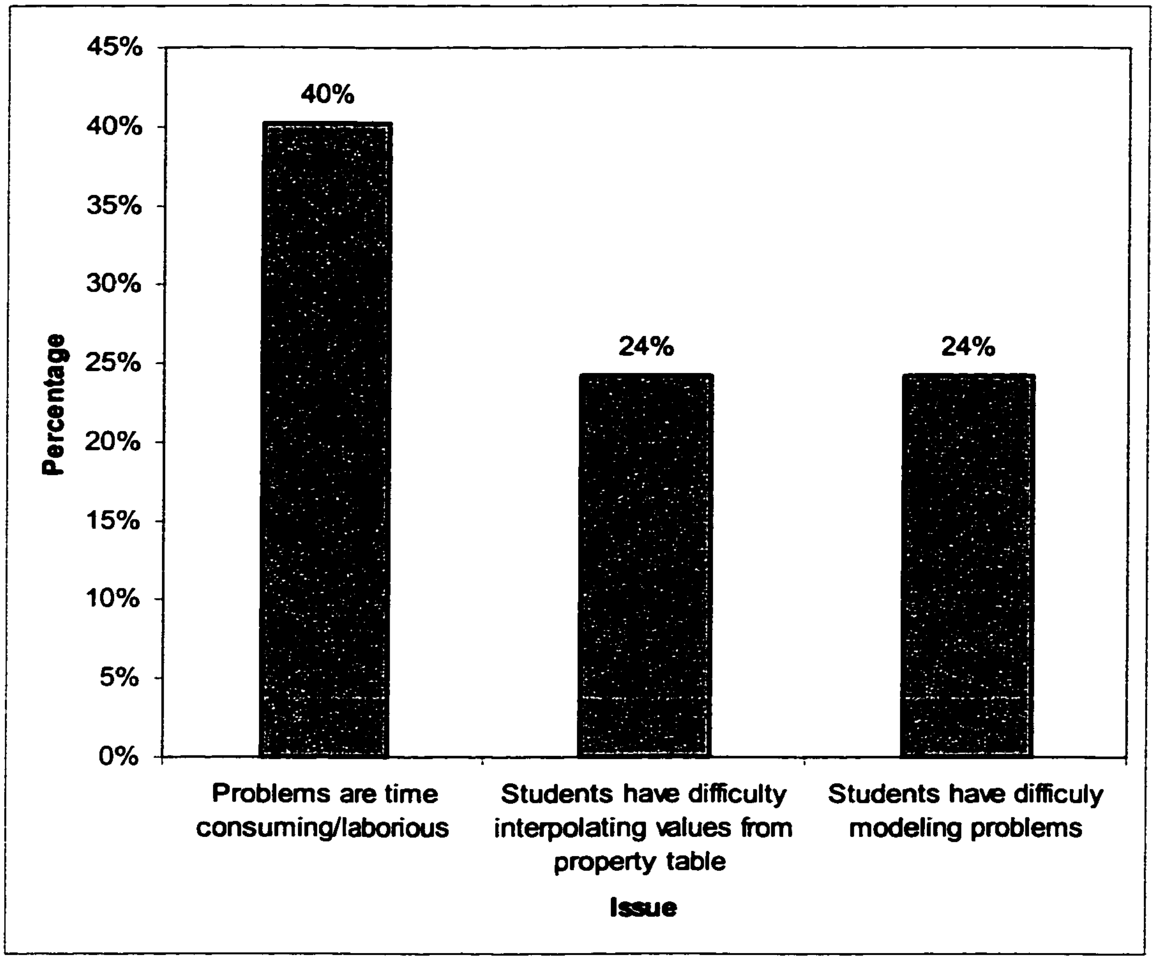
[Students] become familiar with the various quantities that are used in thermodynamics: p, T, V, m, Q, W, etc. They also become familiar with how algebra, and calculus are *used* in science and engineering. Finally, they gain experience with using logic to solve "formal" (well-defined, well-posed) problems. (Professor ID #77)

[Solving problems by hand] forces students to think about every step in the process, make decisions, try equations, etc. Solving problems by hand are open to many incorrect solutions; hence the

> student must develop the skill to correctly apply assumptions and equations. (Professor ID #83)
>
> If properly selected, problems allow for reinforcement of knowledge, application of fundamental analysis tools and comprehension of the material. The use of a problem solving technique assists in the orderly completion of the problems, and the method can be used elsewhere. (Professor ID #94)

Although professors found many benefits to solving problems by hand, they also found drawbacks. Figure 8 shows the top three challenges professors identified in their answers to open-ended questions about the drawbacks and difficulties of student hand problem solving. The most frequent view (40%) was that solving thermodynamics problems by hand was time consuming and laborious. They labeled the repetitive calculations as "tedious" and "frustrating." The second most frequent issue mentioned (24%) was that students have difficulty interpolating values from property tables. Equally (24%) professors felt that students had trouble in making the initial modeling assumptions necessary to setup and solve a problem.

Figure 8: Top three challenges of conventional problem solving




In elaborating on these issues, professors described problems as time consuming to the point where students became either frustrated or bored with the work. In particular, they found property table interpolation to be difficult (as well as time consuming and error-prone). In conceptualizing problems, they found that students did not know where to start and how to model the systems presented. Professors wrote:

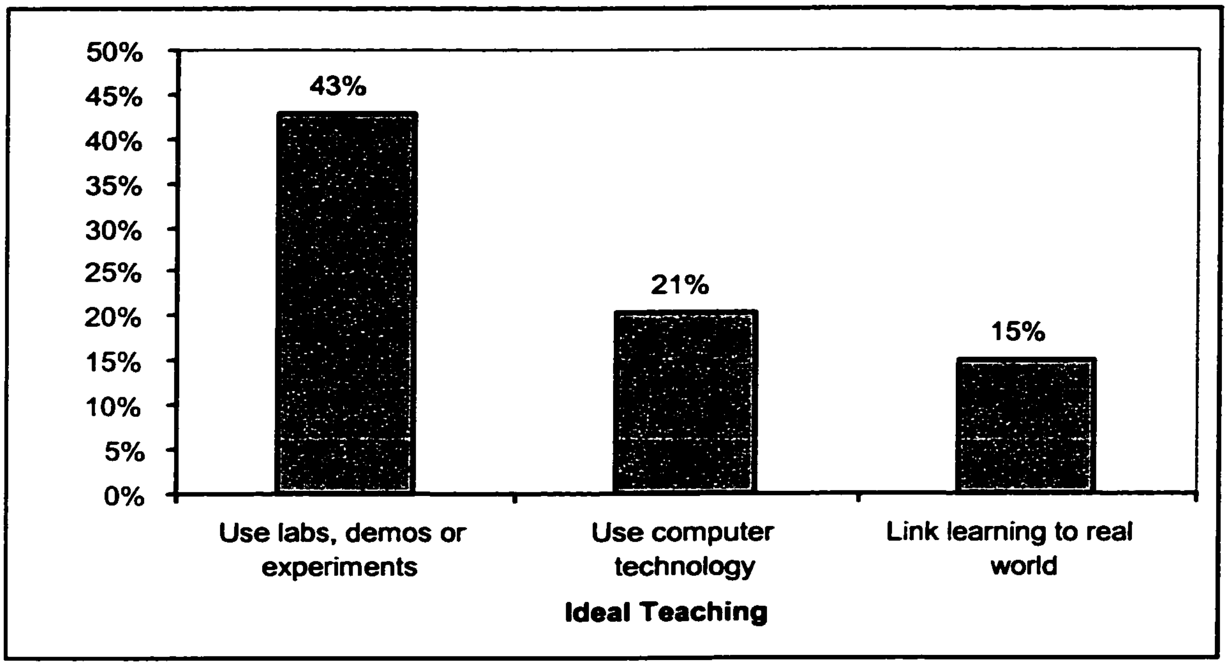
> [Students] make arithmetic mistakes, interpolation errors, [and] misunderstand the type of thermodynamical [sic] tables to be used. [Problems] are time consuming and sometimes frustrate the students. (Professor ID #2)
>
> Where do you start? What to put down? What to analyze? Which equations to use? Snow is an ideal gas isn't it? (Professor ID #18)
>
> The greatest difficulty is knowing where to start on a new type of problem that they have not seen before. They are not good at identifying and formulating the problem. (Professor ID #20)
>
> I think the primary difficulty most have with homework is the modeling step, NOT the computational one. (Professor ID #70)
>
> Too much time spent on calculation detracts from time spent learning thermo concepts. Too often they make errors in hand calcs that tends to be frustrating and has a negative impact on the subject. They tend to think it is too hard to get a right solution. (Professor ID #87)

> Tedium of evaluating properties can mask key concepts illustrated in a problem (Professor ID #90)
>
> [Students have difficulty] figuring out where to start. Applying a systematic methodology to a word statement of a physical situation in order to obtain the appropriate mass, energy, and entropy balances on a control volume. (Professor ID #98)

## Ideal Teaching

While the previous sections described the status quo of thermodynamics teaching, in this section I address the question of what are the professors' ideal visions of teaching thermodynamics. In the survey, professors were asked how they would teach thermodynamics if they had unlimited time and resources. As shown in Figure 9, the most common answer (43%) was to do more laboratories, demonstrations and experiments. Second, 21% of professors wanted to use computer technology such as CAD programs, multimedia, or simulations. Thirdly, professors (15%) would like to create stronger links between the conceptual/theoretical thermodynamics they teach and real world engineering practices. All of these responses point to a desire for greater resources both in materials and in curriculum. The also imply potential changes in pedagogy by doing more hands-on work with actual equipment or computers.

Figure 9: How professors would ideally teach thermodynamics




In professors written responses, they asked for new technologies and laboratory equipment. When describing the usage of these items, they referenced progressive pedagogies such as group work, problem-based learning and reality-based learning. They wrote:

I would love to have some demonstrations to use in class. I have ordered a heat engine kit to make them think about the conversion from heat to work. I have also tried to get a window air conditioning unit to talk about a refrigeration cycle. (Professor ID #13)

More self-directed learning. More historical context (it helped me) on why thermo developed. More hands-on examples (not just labs but real plant). (Professor ID #20)

Let students exercise with simulation programs, confront the students with real plant data, force students to understand theory thoroughly. (Professor ID #26)

Integrate more lab experience with lecture; limited lab resources available at the moment. Perhaps cooperative learning groups and time to have students develop competency in tutored setting. (Professor ID #29)

I would include many demonstrations and/or experiments of processes and hardware, including the development of virtual ones. (Professor ID #36)

> I would like to develop animated processes so student could see what happens. Would like to be able to change a variable and see how that affects the process. (Professor ID #38)

> More experimental demos, more group/collaborative learning experiences, introduction to numerical solutions. (Professor ID #102)

**Professor's Perceptions of students**

While the previous section explored professor's teaching styles, resources and interests, this section discusses their knowledge of their students. The particular areas addressed were: views of student skills and views of student learning of concepts. I was interested in exploring differences in perceptions of students across program types as well as looking at specific skills and concepts to find out which were more difficult to master.

A measure of students' instrumental skills was created that combined five individual measures: performing calculations, determining state, converting units, interpolating properties and applying formulas and equations (Cronbach's alpha =0.72)[15]. Engineering science professors rated their students significantly higher [3.51 (0.53) to 3.29 (0.60), F=2.81] in instrumental skills (see Table 5). One might expect engineering students to perform better on skills that are related to textbook problem solving or mathematics ability as they take calculus earlier in their academic careers than the ET students. Engineering programs are more likely to be at top tier schools where admissions criteria have higher academic achievement.

[15] Items were combined based on conceptual rather than empirical considerations.

Table 5: Professors' ratings of students' instrumental skills

| | mean (standard deviation) | mean (standard deviation) | F |
|---|---|---|---|
| **Instrumental Skills** | **3.29 (0.60)** | **3.51 (0.53)** | **2.81*** |
| ***Individual items*** | | | |
| Perform routine calculations | 3.70 (0.73) | 3.75 (0.74) | 0.08 |
| Given 2 properties (e.g., T, P) determine the state | 3.35 (0.81) | 3.77 (0.83) | 4.27** |
| Convert units | 3.25 (1.02) | 3.39 (0.85) | 0.40 |
| Given 2 properties (e.g., T, P) interpolate other properties | 2.95 (0.69) | 3.43 (0.81) | 6.23*** |
| Apply formulas and equations | 3.20 (0.70) | 3.20 (0.72) | 0.00 |

Scale: 1=very low to 5=very high
*p<=.1, **p<=.05, ***p<=.01

A measure of students' abstract reasoning skills was created that combined ten individual measures as listed in Table 6 (Cronbach's alpha =0.90 )[16]. In general, there was a trend for professors to rate this abstract reasoning skills as lower than instrumental skills. In addition, the ratings for modeling activities (using modeling assumptions to reduce 1st and 2nd law formulas, turning word problems into diagrams or pictograms, knowing where or how to begin solving a problem, making simplifying modeling assumptions) tend towards the low end of the scale. This was consistent with professors' responses to the open-ended questions regarding student difficulties with conventional problem solving (see Figure 8 above).

There were no significant differences in professors' ratings of students' abstract reasoning skills between the two program types. However, the engineering professors rated their students somewhat higher on all but one of the individual items. This, again, could perhaps be due to the higher academic caliber of engineering students entering these schools. One notable exception was professor's responses to the only question in the survey that inquired about students' ability to link problems to real world applications. Here ET professors rated their students higher than engineering professors (see Table 5). Since the ET programs have a greater focus on applied engineering so one might expect ET students to perform better on "hands-on," practical skills.

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[16] See footnote 15.

Unfortunately, this was the only question in this survey to assess this area; the difference is not statistically significant.

Table 6: Professors' ratings of students' abstract reasoning ability

| Construct and Items | Engineering Technology | Engineering | |
|---|---|---|---|
| | mean (standard deviation) | mean (standard deviation) | F |
| **Abstract Reasoning Skills** | **2.57 (0.64)** | **2.78 (0.58)** | **2.02** |
| ***Individual items*** | | | |
| Selecting appropriate formulas | 2.75 (0.64) | 3.05 (0.65) | 3.40* |
| Working through a problem to correct final solution | 2.90 (0.79) | 2.96 (0.61) | 0.16 |
| Using modeling assumptions to reduce 1st and 2nd law formulas | 2.50 (0.69) | 2.93 (0.79) | 4.92** |
| Turning word problems into diagrams or pictograms | 2.40 (0.60) | 2.79 (0.78) | 4.30* |
| Using a logical problem solving methodology | 2.65 (1.09) | 2.98 (0.84) | 0.24 |
| Linking problems to real-world applications | 2.90 (0.97) | 2.79 (0.93) | 2.11 |
| Knowing where or how to begin solving a problem | 2.55 (0.89) | 2.79 (0.76) | 1.50 |
| Making simplifying modeling assumptions | 2.25 (0.64) | 2.67 (0.75) | 5.26** |
| Explain thermodynamics concepts | 2.60 (0.94) | 2.59 (0.75) | 0.00 |
| Solve open-ended problems | 2.32 (0.75) | 2.54 (0.91) | 0.96 |

Scale: 1=very low to 5=very high
*p<=.1, **p<=.05, ***p<=.01

A measure of students' thermodynamics was created that combined ten individual measures as listed in Table 7 (Cronbach's alpha =0.86)[17]. Table 7 shows the results of the analyses for the global construct and individual items. The items are arranged by professors' rating of student ability in descending order from high to low. There were no significant differences found between professors in ET and engineering sciences programs. Again, in individual areas where there were significant differences engineering students tended to be rated higher than their ET peers (2nd law, T-s diagrams). In terms of relative difficulty, professors felt that students have more trouble with concepts related to the 2nd law of thermodynamics (this includes entropy, T-s diagrams and reversibility) as seen by their ranking at the bottom of the list.

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[17] See footnote 15.

Table 7: Professors' ratings of how easy it for students to understand certain concepts.

| **Construct and Items** | **Engineering Technology** | **Engineering** | |
|---|---|---|---|
| | mean (standard deviation) | mean (standard deviation) | F |
| **Thermodynamic Knowledge** | **2.70** | **2.72** | **0.04** |
| ***Individual Items*** | | | |
| Efficiency | 3.40 (0.88) | 3.32 (0.85) | 0.14 |
| 1stlaw of Thermodynamics | 3.15 (0.93) | 3.13 (0.98 | 0.01 |
| Internal energy | 3.00 (1.05) | 3.19 (0.81) | 0.76 |
| Work transfer | 3.00 (0.86) | 2.96 (0.91) | 0.03 |
| Enthalpy | 2.85 (0.99) | 2.74 (0.88) | 0.25 |
| Heat transfer | 2.85 (0.88) | 2.94 (0.94) | 0.15 |
| P-v diagrams | 2.80 (0.83 | 3.01 (0.90) | 0.91 |
| Closed v. open systems | 2.75 (1.02) | 2.85 (1.06) | 0.13 |
| Reversibility | 2.30 (0.86) | 2.14 (0.91) | 0.49 |
| 2ndlaw of Thermodynamics | 2.2 (1.01) | 1.73 (0.77) | 5.45** |
| T-s diagrams | 1.95 (0.97) | 2.47 (0.79) | 6.24*** |
| Entropy | 1.45 (0.15) | 1.54 (0.74) | 0.24 |

Scale: 1=very hard to 5=very easy
*p<=.1, **p<=.05, ***p<=.01

## Conclusion

In examining the two programs - engineering sciences and ET - the ET professors have a greater focus on teaching and their institution supports their teaching activities to a greater degree. The implication of this is that programs such as ET are more likely to be supportive and receptive to pedagogical curricular change. The drawback for these institutions is perhaps a lack of funding to facilitate such innovation.

Professors at engineering schools have a higher perception of their students' abilities. While there could be several explanations for this difference, this area merits further research to determine the generalizability of these results to other topics in engineering and to control for institutional type and student background characteristics. This difference may have implications for technology design and adoption as the perceived needs of the student populations vary.

The current educational practices in thermodynamics could be improved upon. Conventional problem solving, while of benefit for promoting a certain problem solving methodology, reinforcing concepts and illustrating applications of thermodynamics is also time consuming, hampered by property table interpolation and lacking in linkages to the real world. In professors' ideal vision of teaching, they would employ more equipment and technology for hands-on applied-learning. Technology, such as computer simulations and virtual laboratories, would make the routine aspects of problem solving less time consuming while giving students a greater understanding of the behavior of real-world devices.

In terms of the technologies and experiences that professors want to give their students, CyclePad – the technology that this dissertation examines – speaks to the difficulties that they identified with conventional problem solving. It provides students both with computer experience as well as a simulation of actual thermodynamic equipment (much of which is too large or dangerous to use in a school setting). Furthermore, with the knowledge base that underlies Cycle Pad's simulation engine, students can explore all the thermodynamic concepts from the pressure-volume diagrams to enthalpy to entropy as well as gain experience making modeling assumptions. CyclePad includes property table data and calculates values for the student. In these ways, the feature set of CyclePad is in alignment with the needs and goals of many thermodynamic educators.

# CHAPTER 3

# METHODOLOGY

## Case Studies

This dissertation uses case studies of three instructors to create rich accounts of teaching; the intent of which is to understand the complexities of their practices within specific contexts (Huberman & Miles, 1994; Menges & Austin, in press; Miles & Huberman, 1994; Shulman, 1987). Since I believe that the local context will have a large impact on the enactment of curricula, I take a cross-institutional multiple-case study approach. The unit of analysis for these cases is that of the instructor. While each case is embedded in contexts of varying characteristics, they all focus on teaching experiences employing the same technological tool--CyclePad. The multi-site approach will allow for cross-site comparison while still creating an understanding of the individual sites (Crowson, 1993).

## Participants

For this dissertation, I chose to study three instructors. They were selected because they were actively engaged in developing and implementing CyclePad curricula in their classrooms. These instructors had used CyclePad for at least two academic terms, were trying to improve and expand their implementation and were interested in participating in educational research. They had worked and collaborated with our research group for at least two years and were willing to be videotaped while teaching and interviewed about their instructional practices. There were several professors outside of the United States who also met these criteria, however, due to logistical and funding constraints; they are not part of this study.

Table 8 shows the demographics and amount of teaching experience of the three instructors in this study. The instructors' identities are anonymous to protect their privacy. Detailed profiles are located in the respective case studies (chapters four through six).

Table 8: Profile of teaching experience of participants

| | Professor R. | Professor P. | Instructor O. |
|---|---|---|---|
| Position | Full professor | Assistant Professor | Lecturer |
| Tenure | Yes | No | N/A |
| Credentials | Ph.D., University of Illinois, Urbana 1966 | Ph.D., Yale University | Ph.D. candidate, Northwestern University |
| Teaching experience: | | | |
| No. of years | 34 years | 3 years | None |
| Teaching Assistant experience | None | Several years | Several courses |
| Other teaching experience | Second job at Johns Hopkins | Military | Tutoring |
| University | United States Naval Academy (USNA) | University of Arkansas at Little Rock (UALR) | Northwestern University (NWU) |
| College | Division of Engineering and Weapons | College of Information Science and Systems Engineering | Robert McCormack School of Engineering |
| Department | Mechanical Engineering | Engineering Technology and Applied Science | Mechanical Engineering |
| Gender | Male | Male | Male |

## Setting

While the three instructors have in common their usage of CyclePad, the institutions that they teach at differ along many dimensions, e.g.: geography, type of institution, characteristics of the student body, academic mission, and technological resources (see Table 10). One reason for including schools in different geographic regions is that "most discussions of engineering education fail to take into account the astonishing diversity among the various schools, based not only on [school size, ABET regulated curriculum, institution history and traditions, and specialization] but even more on differences relating to geography. Each institution has a synergistic relationship with its local community, drawing many of its students from the area and sending many of its graduates to work in local industries."(Florman, 1996, p. 185). Since this is a study of engineering programs, a professional degree, the local economy is expected to influence what and how content is taught.

Table 9: Institutional comparisons[18]

| | USNA | UALR | NWU |
|---|---|---|---|
| Institutional type | 4-year college | state university | private university |
| Location | Annapolis, MD (33 miles from Washington, D.C., 30 miles from Baltimore) | Little Rock, AK | Evanston, IL North of Chicago |
| Date founded | 1845 | 1927 | 1851 |
| Entrance | Very Difficult | Minimally Difficult | Most Difficult |
| Tuition | free (students must serve in military for five years post-graduation) | $3026 per year (in-state residents) | $22,458 per year |
| Number of student at institution | 3994 | 10,959 full and part-time students | 15,436 students (7,619 undergraduate) |
| Faculty characteristics (number with Ph.D.) | 600 (all full time, 95% with terminal degrees) | 801 (497 full time, 42% with terminal degrees) | 2,649 (80% full time, 100% terminal degrees) |
| Undergraduate: faculty ratio | 7:1 | 15:1 | 9:1 |
| Physical environment | 338 acres small town campus | 150 acres urban campus | 231 acres small town campus |
| Endowment | N/A | $6.5 million | $2.4 billion |
| Research Spending | N/A | $1.8 million | $150 million |

## Subject Matter: Thermodynamics

In general, thermodynamics is the study of energy: its transfer from one location to another or transformation from one form to another (such as work

[18] This information was found at http://www.collegequest.com/

to heat). This can also be explained as the systematic study of the relationship between heat, work, temperature, and energy (Britannica Online, 1998). Thermodynamics is an old science with its roots in the $19^{th}$ century. At that time, the basic laws of thermodynamics were discovered (conservation of energy, processes move towards greater entropy, etc.). The practical applications of thermodynamics include steam power cycles, refrigeration cycles, and gas turbines that are composed of fundamental components such as turbines, pumps and compressors. This science was key in the industrialization of the country. Current research in thermodynamics is at a higher level than what is taught in basic undergraduate courses. Because this is a relatively old science, the content that undergraduate students learn in the introductory courses is the fundamental theories that are accepted by the scientific community as opposed to studying the latest research findings. Thermodynamics is one of the core topics in most of the engineering majors, thus it is required for civil, industrial, mechanical and electrical and chemical engineering students. Often only the mechanical engineering students are required to take courses beyond the introductory sequence.

As shown in Table 10, there is variation as to what topics are covered in similar courses at different institutions. For example, UALR does not teach about entropy in their course. At Northwestern, which is on the quarter system, cycles are not studied until the second thermodynamics course.

Table 10: Comparison of content coverage across courses

| | **Basic Laws** | **Cycles** | **Entropy** |
|---|---|---|---|
| USNA (semesters) Applied Thermal Sciences | X | X | Not covered |
| UALR (semesters) Engineering Thermodynamics | X | X | X |
| NWU (quarters) Thermodynamics I | X | Not covered | X |
| NWU (quarters) Thermodynamics II | (pre-requisite knowledge) | X | (pre-requisite knowledge) |

## Articulate Virtual Laboratories: CyclePad Software

One of the research goals of the *Articulate Virtual Laboratory Project* is to explore how to better support students in developing design skills and building subject matter knowledge. *Articulate Virtual Laboratories* (AVLs) are software programs that can make both conceptual design tasks more accessible to students and provide explanations --the "how" and "why"-- of the science behind their designs (Forbus). To date, two different AVLs have been developed; CyclePad, for university engineering students, and the Feedback Articulate Virtual Laboratory, for high school students. These AVLs include the following software components:

- A *conceptual CAD tool* that students use to generate and analyze their designs.

- A *test environment* that provides a setting for students to run simulations of their designs.

- A set of *visualization tools* to help students understand complex and dynamic relationships.

- An *analysis coach* that helps students evaluate their designs. The coach capitalizes on the latest advances in artificial intelligence, a qualitative reasoner, and an underlying knowledge base of the subject matter to provide advice.

- A *design coach* that makes suggestions for how a student's design might be improved.

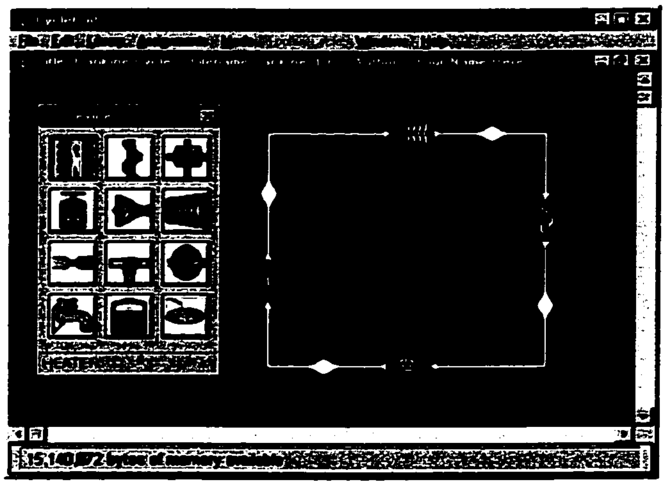

Figure 10: CyclePad's build mode

CyclePad was designed to teach thermodynamics principles by allowing students to build, design and analyze thermodynamic cycles, from Rankine cycles to more complex combined cycles. In *build mode,* students are given a set of components from which to construct a cycle (Figure 10). After they have built their cycle, they work in *analysis mode* to make modeling assumptions about processes and components (e.g., heaters and turbines) and their associated inlet and outlet states. Once the student has specified enough of a cycle, CyclePad can calculate the remaining values. Student can access CyclePad's underlying knowledge base to find out how a value was derived or to ask what data is needed in order to complete a calculation. For example, students can ask questions such as "Why does the efficiency equal 48%?" or "How can I compute shaft power for the turbine?" Then CyclePad shows the formulas, assumptions and numbers used (or needed) to arrive at those values. The student can continue to query CyclePad's answers to follow its chain of reasoning.

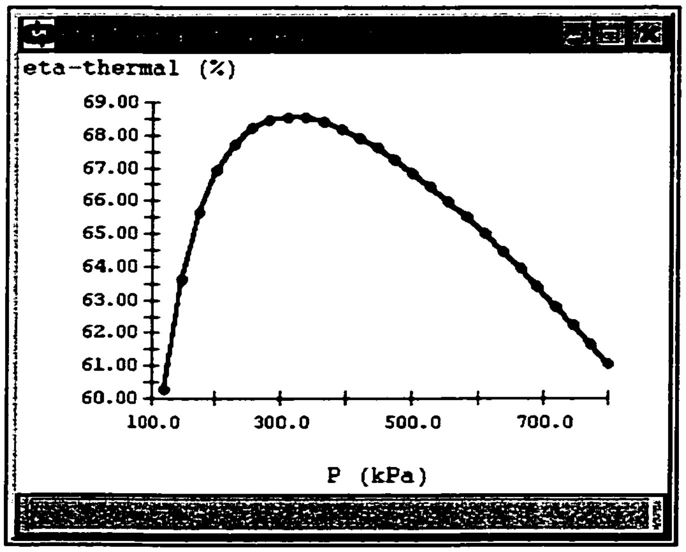


Figure 11: CyclePad's sensitivity tool

Unlike other thermodynamics software, CyclePad has a number of tools to help students understand the relationships between parameters (Forbus, 1997). The sensitivity tool (Figure 11) permits a student to see how a parameter is affected by varying another parameter, e.g., how thermal efficiency varies with the pressure at a certain state point. CyclePad can also notify the student when it detects contradictory design assumptions and force the student to make changes. Students can compare cycles using different substances including ideal gases, water, R232 and methane. The program has an economic model that students use to calculate the real-world costs of building and operating systems. The combination of these features lets students design and analyze simple to complex cycle. In our design of CyclePad, our goals were to:

- Enable students to design, make conjectures, and explore possibilities in cycles
- Serve as a monitoring aid during the problem solving process
- Free students from the burden of tedious numerical and algebraic manipulations, thus providing time for focusing on broader concepts
- Allow students to investigate designs to develop their conceptual understanding
- Focus students on the importance of making assumptions in engineering problems

## Instruments and Data Collection

Several methods were used to document teaching practices: interviews, classroom observations and artifact analysis. Multiple approaches are necessary to be able to query the instructors about what was observed in the classroom and to learn more about their personal histories, values and teaching beliefs due to the tacit nature of teacher's pedagogical knowledge (Lenze, 1995).

## Interviews

A semi-structured approach was used for interviews. An initial list of questions was developed based on those used in Grossman's study of new high school English teachers (Grossman, 1990). These questions were modified to apply to engineering schools and thermodynamics courses. In practice, the list of questions (see Appendix A) was used as a guideline to make sure all areas were covered in conversations. Interviews typically took place in hour-long sessions, often several times in the course of two or three days. For the instructor based at Northwestern, these conversations were spread out over the course of an academic term. Topics covered were:

- Knowledge/conceptions of thermodynamics and teaching thermodynamics

- Prior experiences that influence teaching practices
- Views on engineering education and personal history
- Pre-semester - curriculum planning
- Post-semester – reflections on CyclePad experience

Each participant responded to the questions in terms of what was critical or most important to his or her conceptualization of teaching; hence, the responses were highly individualistic. For the two remote locations, interviews occurred during site visits, via telephone, and through e-mail. Interviews took place during the term with the exception of the post-semester interview that took place in the following term. All interviews were tape-recorded and transcribed. Included in this was also e-mail correspondence between the researcher and the participants.

## Observations

I observed each instructor teaching a minimum of eight times over the course of this study. I made fewer observations at the remote locations due to logistical constraints with travel. I tried to observe the instructors teaching the same topics (lectures and labs on Diesel or Otto cycles[19]) to have some consistency across sites. I observed class periods in which CyclePad was used as well as those that were just lectures. I took field notes and videotaped some of the classroom visits. When videotaping the classes, one camera was used which was primarily focused on the instructor but also included some instructor-student interactions (if any occurred). All videotapes were transcribed and later coded as described below in this chapter.

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[19] These are two specific closed cycles taught in all three of the courses. I chose these because they are cycles used in automobiles and thus have the potential of being linked to real-world systems that are familiar to students.

## Artifact Collection

At all sites, I collected several types of artifacts: syllabi, assignments, textbooks and student work (see Table 11). Other items that were relevant to CyclePad usage, such as journal papers about CyclePad or professor's surveys of students, were collected when available. All items were coded and the results were compiled into the composite reports.

Table 11: Artifacts collected

| | Professor R. (USNA) | Professor P. (UALR) | Instructor O. (NWU) |
|---|---|---|---|
| Syllabi | X | X | X |
| Assignments | X | X | X |
| Student work | X | X | X |
| E-mail correspondence | X | X | X |
| Textbook | X | X | X |
| Course web pages | N/A | X | X |
| Student surveys | X | X | X |
| Publications: Published journal articles | X | N/A | N/A |
| Conference papers | X | X | N/A |
| Working papers | X | X | N/A |

## Data Collection

Data was collected between 1996 and 1999, as detailed in Table 12 and Table 13.

Table 12: Data Collection by school year

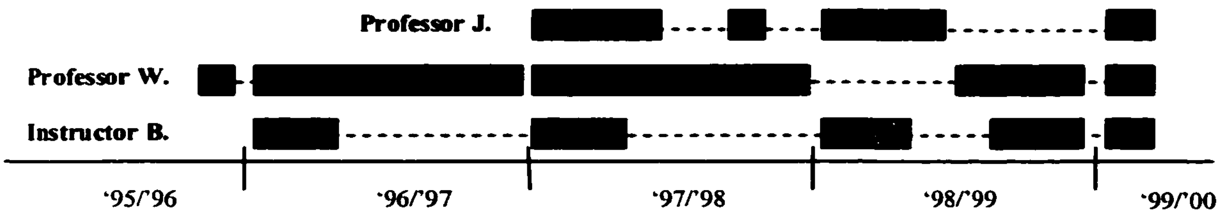


Table 13: Data collection details

| Year | Professor R. (USNA) | Professor P. (UALR) | Instructor O. (NWU) |
|---|---|---|---|
| 1996-97 | *Engineering Thermodynamics* (Fall, Spring)<br>*Energy Conversion* (Spring)<br>• student surveys<br>• meetings | N/A | *Thermodynamics II*(Fall)<br>• student surveys<br>*Thermodynamics I* (Spring)<br>• student surveys<br>Study of several students using CyclePad (Summer)<br>• student observations<br>• student surveys<br>• artifact collection |
| 1997-98 | *Engineering Thermodynamics* (Fall),<br>*Energy Conversion* (Spring)<br>• classroom observations<br>• student surveys<br>• artifact collection<br>• interviews | Applied Thermal Science (Fall)<br>• classroom observations<br>• student surveys<br>• artifact collection<br>• interviews | *Thermodynamics II*(Fall)<br>• classroom observations<br>• student surveys<br>• artifact collection |

| | | | |
|---|---|---|---|
| 1998-99 | *Engineering Thermodynamics* (Spring), *Energy Conversion* (Spring)<br>• classroom observations<br>• student surveys<br>• artifact collection<br>• interviews | Applied Thermal Science (Fall)<br>• classroom observations<br>• student surveys<br>• artifact collection<br>• interviews (in Spring too) | *Thermodynamics II*(Fall)<br>• classroom observations<br>• student surveys<br>• artifact collection<br>*Thermodynamics I* (Spring)<br>• classroom observations<br>• student surveys<br>• artifact collection<br>• interviews (Summer) |

## Data Analysis

The method for coding the data is described below. This method was used to code all types of data regardless of the source (i.e., interview, survey, artifact or observation). The multiple sources of data were used for triangulation. By using the same coding scheme across all types of data, I was able to see whether patterns and themes persisted from one source to another. For example, classroom observations were compared with instructor's descriptions of their teaching in interviews and via e-mail. Student surveys provided an additional perspective on the classroom experience. At two of the schools, the instructors taught two sections of the same course. This allowed me to look for consistency in teaching between classroom observations of the same lessons.

## Initial Coding

For an initial coding scheme, I used Grossman's four categories of pedagogical content knowledge --goals and purposes for teaching, knowledge of students, curriculum and instruction. I created subcategories for these topics as they emerged in the data as shown in Table 14. Using this scheme, I coded each individual idea or thought. Where appropriate, multiple codes were applied. I started with this initial coding scheme to analyze the data from UALR. In doing so, other codes emerged that were beyond the scope of Grossman's model. For example, I developed codes specific to CyclePad and technology that I added to my coding scheme.

Table 14: Coding Scheme example

| |
|---|
| **Knowledge of Conceptions and Purposes for Teaching Thermodynamics with CyclePad** |
| Goals and purpose |
| Ideas |
| Course specific |
| What it isn't good for: |
| Email problems |
| **Knowledge of CyclePad-based Curriculum** |
| Textbook critique/criticism |
| Sequencing |
| Course integration |
| Curriculum development |
| Horizontal integration |
| Vertical integration |
| Curricular Issues with CP |
| **Knowledge of Instructional Strategies with CyclePad** |
| Tepresentations |
| Instructional strategies |
| Motivation & instruction |
| Grading |
| **Teaching Specific concepts with CyclePad** |
| Critique of current teaching |
| Course description |
| **Context** |
| Department politics/structure |
| School level |
| Students |
| **Students** |
| Student learning |
| Student motivation |
| Miseducation |
| Misconceptions |
| **Ideal teaching** |
| Critique of current teaching |
| **Instructor's background** |

**Refined Coding**

The resultant coding scheme was then used to analyze the other two cases. Again, as needed, I created new codes to account for data that did not fit within the original scheme. Many of the new codes were specific to the educational institution. For example, at UALR, I needed codes that related to engineering technology. At USNA, there I needed codes relating to using CyclePad in research. These new codes I added to the scheme and used to re-code certain bits of data in the previous cases.

**Composite Reports**

After initial coding of all documents (interviews, observations and artifacts) for each case, I created a document organized by the topics used in the coding scheme. Under each topic, I summarized the respective data, indicating the location of the original source material. Thus, for any one summary idea, I might list several pieces of data. By clustering the data, I could distinguish between isolated instances of an event or thought and larger patterns. Patterns were defined as multiple instances that were about a similar topic (Miles & Huberman, 1994).

**Trustworthiness**

Throughout the two years I have been working on this project, I have shared the results of my research with those involved. At various points, the three instructors have reviewed conference papers and journal articles about their classrooms. Additionally, I have submitted conference paper proposals with both Professors R. and P. They also were given the opportunity to read rafts of the chapters in this dissertation to check accuracy clarify points and provide feedback.

## Data Presentation

Each case is presented in a separate chapter, beginning with a profile of the participant. The profile includes the instructor's demographics, past teaching experience, work setting at the time of the study, and personal goals and preferences. I describe the teaching context: university, department, classroom and students. Following this, I discuss the CyclePad implementation in terms of the curriculum developed and instructional strategies used. I discuss how their knowledge of students is a guiding force in the instructional and curricular decisions they make. The final section of each case chapter presents a contrast between the professors' enacted CyclePad curriculum and their ideal vision of how the software could be implemented.

# CHAPTER 4

## PROFESSOR P. AT UALR

This case is an example of narrow curricular usage of CyclePad with a goal of integrating it broadly into the curriculum. The context of use is within an engineering technology program rather than engineering sciences. The professor perceives the program context as requiring a greater focus on hands-on applied teaching of thermodynamics. The professor, in his third year of teaching, is an innovator-- finding creative ways to integrate CyclePad with other educational software products and innovative pedagogies. Yet, in striving towards his ideal vision of teaching thermodynamics, other forces at the university compete for his time and energy and thus he doesn't fully integrate CyclePad into the curriculum.

This chapter begins with a description of the professor and his work context. This is followed by an analysis of his teaching with CyclePad and his ideal vision of teaching. The chapter concludes with a comparison of his real versus ideal teaching.

## Instructor Profile

Professor P. met our research group in the summer of 1997 at the American Association for Engineering Education (ASEE) National Conference in Milwaukee. While at the conference, he saw a demonstration of CyclePad and became interested in collaborating with our research group. He had recently received his Ph.D. from Yale University in Mechanical Engineering and, at the point of our first meeting, was about to begin his second year of teaching at the University of Arkansas at Little Rock (UALR). He felt a connection to our research group as he done his undergraduate work in Mechanical Engineering at Northwestern University and had spent several summers living in the Chicago area and working at Argonne National Laboratory.

### Entry into Teaching

After graduating in 1982 with a B.S.M.E. from Northwestern (where he was a ROTC student), Professor P. served as an officer on a nuclear submarine in the U.S. Navy. At the U.S. Navy Leadership and Management Instructor School he learned pedagogical theories, principles of leadership and management and had the opportunity to practice teaching. He graduated from this program with academic distinction, ranking first of ten. Afterwards, he spent three years as a Submarine Officers Basic Course Instructor at the U.S. Naval Submarine School where he taught submarine engineering and tactical systems, operations, and leadership and management courses. He was selected as "Instructor of the Quarter" during this experience.

He describes his military service as the only formal training in pedagogy that he received before becoming a professor:

> The Navy is really into curriculum development and instructional methods and so we [had] learning objectives for everything. It's very laid out and organized before anything gets taught. So I had instructor training for ten weeks -- which is ten weeks longer than most grad students! -- and then I taught full time. I learned all kinds of things in that environment, but no teacher I ever had did those things. (Professor P. Interview September 1998; tape 3 p. 3)

Professor P.'s teaching experience continued as a graduate student at Yale where he taught several different courses (as both a teaching fellow and a part-time acting instructor) including Fluid and Thermal Energy Science. Professor P.'s father is a retired professor of mechanical engineering. When asked whether his father had pushed him towards a similar career, Professor P. said that his father had probably encouraged him to study engineering but not necessarily to become a professor. When it came time to apply for jobs while finishing his Ph.D., Professor P. considered teaching positions at both colleges and private high schools. He had two job offers, one from a private New England high school and the other, which he accepted, at UALR. In my discussion with Professor P., he made it clear that he was more interested in teaching than in research (although he said he was interested in research on education). Of the instructors in the three cases presented here, he was the only one who read the engineering education journals (e.g., Prism, Journal of Engineering Education, and Journal of Engineering Technology). He was happy with his decision to come to UALR as he and his wife had family in the southern U.S.; however, he mentioned longingly that 1997 had been a bad year for academic positions and that the current job market (1999) held many more opportunities for doctorates.

## Professional Context

### University

UALR is a state school with approximately 10,000 full and part-time students and over four hundred full-time faculty members. It is located on 150 forested acres just fifteen minutes from downtown Little Rock. Despite being located in the state capital, UALR has secondary status to the University of Arkansas at Fayetteville (UAF) branch. Historically, this has led to preferential treatment for UAF in policy matters (as many of the state politicians are UAF graduates).

In 1999, the university board approved the expansion of UALR's engineering school with the addition of a new department with two new majors at UALR. In many of my discussions with Professor NJ, he discussed the uncertainty of his potential role in the proposed new school. Professor P.

wasn't sure if he would end up working in the new department or staying in his current department. He feared that if he switched to the new school, that his tenure clock would be reset.

**Department/College**

Professor P. holds a joint appointment in Engineering Technology and Applied Science in the College of Science and Engineering Technology. While engineering degrees prepare students to be researchers and designers, engineering technology (ET) degrees are intended for technologists who run machinery and hold the types of jobs that require more "hands-on" knowledge rather than theoretical knowledge.

Professor P. felt that being part of an ET program had pedagogical implications for which his prior experience and training did not provide useful examples or role models. He explained that:

> So almost all of us [the professors] come out of engineering programs. So when you teach a course in thermo you tend to do it

> the way you were taught. ...I don't think engineering technology should just be engineering minus the math. That's, to me, not worth having. It should be engineering minus the math plus something. And the something is supposed to be practice oriented, hands-on ... (Professor P. Interview September 1998; tape 6 p. 4)

Professor P. felt that ET as a field had missed its chance to significantly differentiate itself from engineering as engineering programs were changing to be more hands-on by requiring students to do more design and laboratory work. He was frustrated that recent legislation had changed the rules about eligibility for the Professional Engineering (PE) exam by disallowing engineering technology students to sit for the exam. While the certification is not necessary for all jobs, the decision served to lessen the value of an engineering technology degree. He lamented that the future of the ET degree was uncertain and that it had missed an earlier opportunity to differentiate the degree from engineering science. He explained:

So, in the minds of most people, and it is probably the truth, is that engineering technology is more like engineering minus something. It's hard to find the plus the part that our students get that engineering students don't. Especially since engineering programs have shifted with more of a design emphasis, so they are more practice oriented. Basically we didn't fulfill the needs of industry to create practicing engineers, so they went back to engineering programs and said you guys have got to be more practice oriented, this research emphasis is killing us. Your graduates come us and they can't do anything. We need to be able to hire people who can do something from the beginning--produce. So they listened and added in the professional design and the capstone design, the accreditation has changed to require that --, and basically engineering technology then loses its reason for existence. So that's why 18 states now don't let engineering technology graduates even sit for the PE exam, even though in the original scheme of things engineering technologists should have been more oriented towards

> that -- but it never turned out. (Professor P. interview September 1998; tape 6 p. 4)

With the potential changes looming for the department, Professor P. speculated that the mechanical engineering technology program might try for engineering accreditation in the future.

**Course and Classroom**

For this dissertation, I followed Professor P.'s teaching of *Applied Thermal Sciences* in fall term of both 1997 and 1998. In terms of content coverage, the course is analogous to the full year thermodynamics course sequence taught in engineering sciences programs. The class met in both a regular classroom (rows of desks with blackboard in front) and, on lab days, in a room with approximately thirty Pentium computers arranged on long tables four rows deep.

*Research in the classroom*

Professor P. was beginning to use his teaching as a site for doing research. He won an award at a regional ASEE conference for paper he wrote that was about using CyclePad in his '97 Applied Thermal Sciences course. He had also submitted a paper to the Journal of Engineering Technology (JET) but he described it as "sort of anecdotal – [I] compared the student evaluations form one year to another." JET was interested in the paper but asked for major changes. While Professor R.'s teaching-related research focused on curriculum development, Professor P. was interested in student learning.

He explained the difficulty of doing research at a state school that had a dual mission:

> It's kind of a chicken-egg situation. [The administration] says "if you get the grant we'll give you release time" but if I don't have release time how can I do the preliminary research to get the grant? You need preliminary research to get a grant now a day. Some people would prefer it to be a teaching place but some people

> would prefer to see a certain segment shift to research. (Professor P. Interview September 1998; tape 2 p. 9)[20]

For these reasons, educational research fit better into Professor P.'s professional career than engineering research as he has a higher teaching load than professors do at research universities. The tension between research and teaching at UALR is common to other state colleges and comprehensive universities where there is a high commitment to teaching, yet also institutional hopes of developing the prestige of a research university (Austin, 1992).

**Students**

In the classes that I observed, the students were predominantly white and male. The class size was small, typically between ten and twelve students. The average age of the UALR students is 27, so many have had experience in the

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[20] Professor P. can't increase his salary by getting grants. This reduces the incentive to do research compared with NWU (Professor P. Interview September 1998; tape 3 p. 1)

work force and continue to work as they attend school (often called "non-traditional" students). Many of the mechanical engineering technology (MET) majors are employed full-time in engineering-related fields. They see the ET degree as a pathway to higher paying, more upwardly mobile careers.

## Teaching with CyclePad

In this section I focus on Professor P.'s actual implementation of CyclePad in his classroom. There were three important ways in which he integrated the software into his curriculum:

- as another form of representing the subject matter to his students
- with another software program to promote literacy
- as a link to students' prior knowledge of the world

### Instruction: New Forms of Representations

Professor P. was informed about educational research from several sources including the publications of American Association for Engineering Education (i.e., Prism, and the Journal of Engineering Education) and the Journal of Engineering Technology. He mentioned studies he had read about how using multiple instructional methods can benefit students by offering them multiple ways (e.g., text, class, or web) to learn material. He explained:

> [Students] can listen to lecture, they do interactive things in class, they can listen to a video on the web, they can read the textbook, and they can read text on the web. All these different ways of dealing with the course material give them an opportunity to learn in a way that fits their learning style. (Professor P. Interview September 1998; tape 3 p. 3)

For this reason, Professor P. kept informed about new technologies and trends and felt it was important to incorporate new programs in his classes.

Professor P. was particularly interested in finding educational resources for *Applied Thermal Sciences*. UALR lacked relevant laboratory equipment and adequate budget to purchase the costly equipment necessary for thermodynamics laboratories. Professor P. had seen laboratory equipment at the ASEE conference but it cost over ten thousand dollars, which he knew was far beyond the reach of the department's resources. When he saw the CyclePad software, Professor P. was looking for something that could give his students a "hands-on" experience in his Applied Thermal Science course -- a course designed to be equal parts lecture and part laboratory. He thought CyclePad could be used for the laboratory part of the course. He wrote to me in e-mail:

> We don't have an engine laboratory, a gas turbine laboratory, or a steam plant laboratory, so CyclePad will give [the students] a virtual laboratory experience with these cycles. I hope that CyclePad helps them see the big picture of thermodynamic cycle analysis, by letting them avoid repetitive and tedious process calculations. (From e-mail 9/11/98)

Part of the need for other approaches to thermodynamics arose from the nature of the program in which Professor P. teaches. Engineering technology students have a much lower mathematical background than engineering sciences students. The ET students are still learning algebra while the latter group is into calculus. The ET approach to thermodynamics is watered down in terms of the level of mathematics that it expects students to know and exposes students to. Without knowledge of calculus, it does not make sense to spend class time deriving formulas and explaining proofs (which use derivatives and integrals). Professor P. felt students could instead use the time to experiment with CyclePad and "quite possibly, learn more about thermodynamics as a result."[21] Professor P. felt that understanding thermodynamics from a qualitative perspective is of value, even more valuable than a quantitative perspective, for the students' future work in industry. He explained his pragmatic position:

> In industry you're going to have computers codes that do almost all the number crunching..."Well, do you like the number that the computer gave you?" "How else can I model it?" -- those are qualitative decisions not quantitative ones. ... It's the qualitative

---

[21] From Professor P.'s conference paper.

> model building that is the real key. I think it's possible to learn a lot more about thermodynamics with CyclePad than the way I learned it, very quickly. (Professor P. Interview September 1998; tape 1 p. 8-9)

Professor P. wanted students to be able to link the intuitions that they gained from using CyclePad with mathematics. He would have students experiment first with CyclePad and then in a later class he would explain the mathematics behind what they had experienced. He explained his rationale of this pedagogical approach:

> I think it [the formulas] will mean more to them after they experiment with CyclePad and they say, "What affects efficiency[22]?" and then next week, we're going to derive some of those formulas for efficiency and it will show that, "Hey here's this formula that shows that, yes, it is the compression ratio and you found that when you did your experiments." And I think that will

> be more meaningful to them, seeing that second, rather than first. It's all sort of experimenting in the virtual lab and [finding] that out for themselves. [Then] the power of equations confirms that. (Professor P. Interview September 1998; tape 6 p. 1)

For example, in one class, Professor P. had his students create pressure-volume (P-v) plots of cycles and then try to build them in CyclePad. Although they struggled with the task, Professor P. felt that it was good for the students to try to see the connection between the graphs and the computer so that they understand that the graphs have meaning. He told me that he would use a later class period to explain how to interpret graphs and CyclePad models. He felt that since the students had struggled with the task, they would be more invested in the process and get more out of his explanation.

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[22] A measure of cycle performance.

**Literacy: WebCT and CyclePad**

Professor P. had read about WebCT[23] (a tool that facilitates the creation of sophisticated web-based educational environments by non-technical users) in the Chronicle of Higher Education, downloaded it and "appointed" himself to be the university WebCT administrator over the summer of 1998. He received summer funding from the university to implement WebCT and money to arrange for a site license. In addition to using the software for his courses, he trained other professors and instructors on how to create on-line materials for their courses.

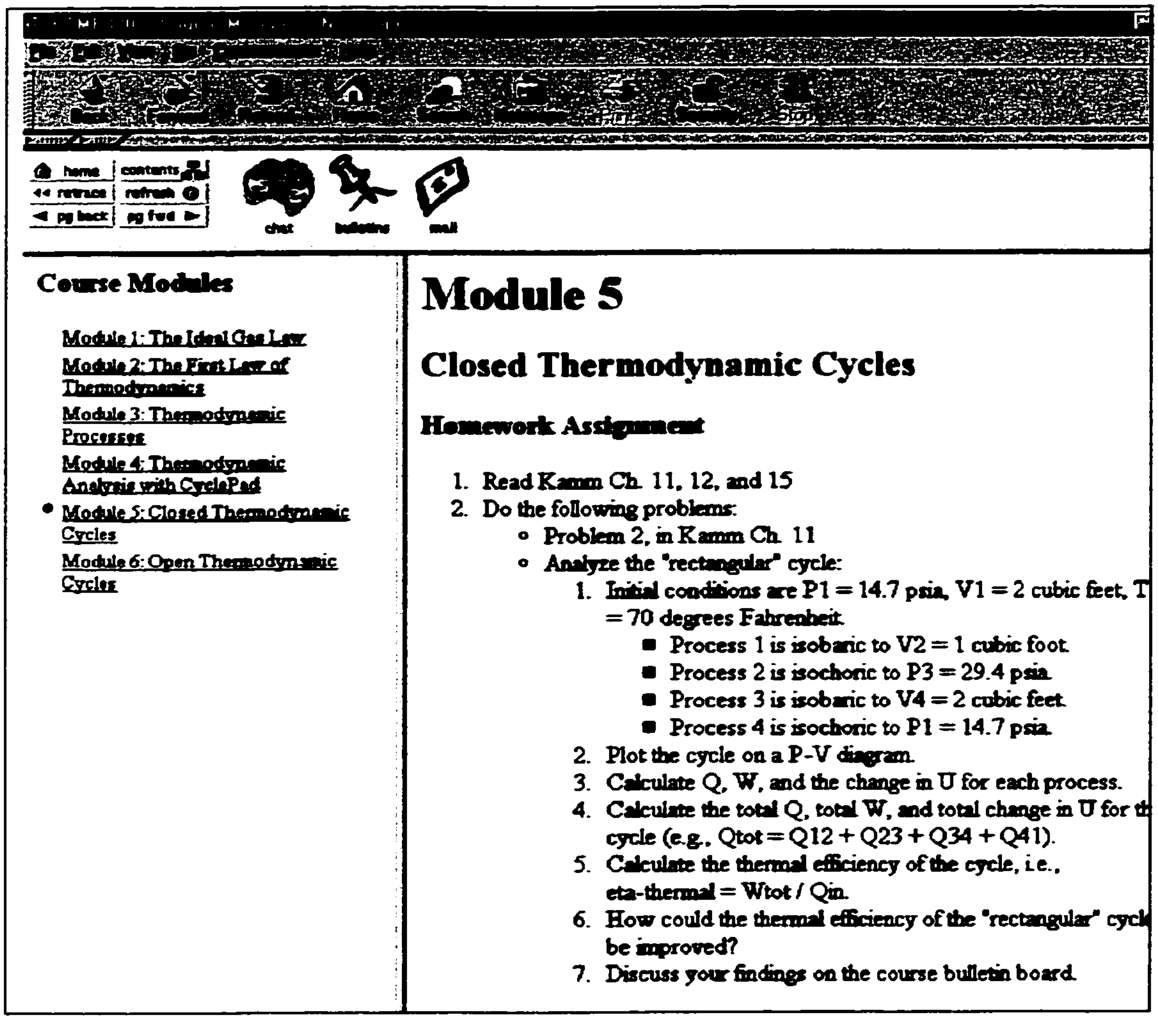
He felt that WebCT benefited professors, and himself, by allowing instructors to concentrate on the course content rather than having to learn how to program HTML. The software has structures built into it to make it easy to create course pages that can include syllabi, curriculum modules, on-line exams and other links. In addition to automating web page creation, WebCT has several built-in communication packages that allow for course

[23] WebCT is now owned by Universal Learning Technology in Cambridge, MA

bulletin boards, e-mail, and chat. Students can also create their own web pages and put their presentations and papers on-line. Professor P. used all of these features when he put his 1998/99 Applied Thermal Sciences course on-line.

Figure 12 shows an example of one of the modules that Professor P. created in WebCT. In this example, he created a homework assignment in which students read textbook chapters that include content on engines and engine optimization and then analyze a similar system in CyclePad. The students are asked to post and discuss their answers in WebCT's bulletin board.

**Figure 12: One of Professor P.'s WebCT modules on CyclePad**



Educational Goal: Literacy

Threaded through Professor P.'s instructional strategies is the combining of his goals of content understanding with literacy practice. Professor P. wanted to improve upon the typical engineering course in which students are graded on getting the right answer and not encouraged to write up their homework or lab work using anything besides formulas and numbers.

In his second year of teaching, Professor P. became concerned with students' literacy. At a meeting of the Mechanical Engineering Technology Industrial Advisory Committee, Professor P. "heard there … that communications, teamwork, and 'people skills' are at least as important as engineering skills."[24] It became his mission in each course he taught to link literacy skills with content knowledge. He explained how shocked he was by his students' lack of verbal skills:

> How can this person have a high school diploma? How can this person be admitted to college? How can I teach engineering if they

> are at a third grade reading level? ... I'm not one hundred percent sure in my advanced classes that there aren't some people who can't read. I mean, they have very, very remedial reading but not sophisticated. I started [assigning papers]... first in my freshman class, they were so atrocious, and I thought, "Am I sending people on to get degrees that can't do any better than this with language?" That really gave me a problem because I don't really know if I can live with myself if I'm part of that. ...That's partly why I like the WebCT and the student presentation part of it. (Professor P. Interview September 1998; tape 7 p. 3)

He felt that verbal skills were important today because the nature of engineering had changed. He experienced this personally in the Navy where he told me, "All I did was communicate. The enlisted guys did all the work with the valves.... I just did paperwork."[25] He elaborated:

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[24] From e-mail to me 9/11/88
[25] From Professor P. Interview September 1998; tape 2 p. 7

When I was a kid, engineers used to use slide rules. So what did graduate engineers used to do? They got assigned to a little cubicle somewhere -- like a civil engineer might do stress calculations on a bridge and compute the reaction loads at each joint. It's just tedious mundane calculations just over and over from one end of the bridge to the other; they'd just do it by hand. There's a certain social personality that would be attracted to that kind of work isolated from others, doing repetitive work. But computers do all that stuff now, so engineers -- whether engineering technology or engineering science students -- mainly what they do is communicate by e-mail, phone, technical reports, proposals, [and] web pages. That's mostly what the job is. That's why I added those [the projects/papers] in because I feel like I have to have more. I'll have everybody write and speak in my classes and I'll have done my part. When students graduate from college, they will have worked on some of these skills. (Professor P. Interview September 1998; tape 2 p. 7)

In the 1998/99 school year, WebCT became instrumental to Professor P.'s desire to improve the communication skills of his students. His belief that a program like WebCT could help students improve and practice their communication skills was founded on studies of distance learning that he had read which found that students did more writing and learned more by practicing writing. Although his course was not a distance-learning course, he felt that the students could still reap the same benefit from being required to use the features of WebCT.

<u>On-line Discussions</u>

Professor P. used the bulletin boards for students to post laboratory results and get feedback. He tried to give students feedback that might engage students in discussion rather than offering remediation. For example, students were asked to investigate the relationship between the compression-ratio and efficiency in a Diesel cycle using CyclePad. Professor P. asked them to post their results to the class bulletin board He explained: "I ask them questions, trying to provoke more discussions rather than confirm or deny their findings[26]." Professor P.'s teaching strategy is illustrated in the excerpt from the class bulletin board in Figure 13. This provides a clear example of how Professor P. paired the two technologies.

Figure 13: Bulletin board discussion of CyclePad lab

| **Postings** | **Commentary** |
|---|---|
| *posted by Student1 on Tues, Sep. 22, 1998, 14:36*<br>Subject: Diesel Cycle<br><br>If the compression-ratio increases, the efficiency will increase. If the temperature in state one is increased, the efficiency will also increase. If the mass in state one is increased, the efficiency will also increase.<br><br>Findings by: Student1 and Student2 | Students post their results for the problem. |
| *posted by Professor P. on Wed, Sep. 23, 1998, 19:59*<br>Subject: re: Diesel Cycle<br><br>Is this different from the Otto cycle? Do others agree with these findings? Did anyone else find other parameters that affect the efficiency of a Diesel engine?<br><br>-Professor P. | Professor P. responds by asking questions that try to link the students findings with what they've been studying in class and trying to engage others in the discussion |
| *posted by Student 3 on Wed, Sep. 23, 1998, 20:55*<br>Subject: re: Diesel Cycle<br><br>Of the choices provided, the three variables mentioned by Student1 and Student2 where the only ones that potentially increased eta-thermal that I found. So, I concur with their findings. As far as differing from the Otto cycle, the Diesel cycle has more variables determining the thermal efficiency (rc for Otto, rc, mass, and temp for Diesel). | Another student responds with his results and comments on the first group's answer. |

[26] From Professor P. Interview September 1998; tape 6 p. 2

| Postings | Commentary |
|---|---|
| -Student3 | |

## Connecting with Prior Knowledge

While Professor P.'s students may be weak in basic skills, they do come with other knowledge. He was aware that many knew a lot about cars and wanted to link this with the content of Applied Thermal Science. He said:

> Connecting what they already know about hydraulics, about their car engines to this scientific knowledge -- that's my job. If I can make that connection for them then that will make this all more meaningful. For me the closed cycles [Otto, Diesel] are kind of important because what they are actually more familiar with is their car. They'll know what the intake stroke is, the pressure stroke and the power stroke and the exhaust stroke. They know that they understand the connection between the mechanisms -- not all of them but a good number -- a good number of them know that kind of thing and have taken apart and added a supercharger. A lot of

> them have a feel for that. (Professor P. Interview September 1998; tape 8 p. 1)

Professor P. made certain decisions about how to order the curriculum based on what he knew about motivating his students. He felt that they were turned off by abstract concepts so he taught them "real" cycles (e.g., Otto, Diesel) before teaching the Carnot cycle (a theoretical cycle which is usually the first cycle explained in thermodynamics textbooks). He described how the course went:

> I sort of blew through the first chapter. And the students weren't very comfortable with that but the students weren't very comfortable the year before either when I slowed way down. All it did last year was prolong the agony because we didn't get to talk about – I mean, they actually like it when we get to talk about airplane engines and car engines and refrigerators. They are more interested when you start talking about that sort of thing. The way the book is laid out, it's like this building block approach and

> they're not really interested in a constant volume process. And so my attitude is that I'm going to blow through that as fast as possible and we'll continue talking about the processes because that's what makes up the cycles so they'll get more comfortable with those. (Interview January 13, 1999; tape 9 p. 7)

### Professor P.'s Ideal of Teaching with CyclePad

Professor P. thought that the students get "bogged down in detail and lose the big picture" with the "building block approach" that their textbook used.[27] He criticized current textbooks as boring and uninspired in their logical sequence of building from individual processes up to complex cycles. In his ideal thermodynamics course he would abandon the structure of the textbook and restructure the course to start with cycles. He explained that he would start with Cycle Pad's Solved Otto Cycle (since his students already have

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[27] From Professor P. Interview September 1998; tape 8 p. 1

knowledge of car engines) and then he could explain the individual processes He said:

> I'm still thinking that next year when I teach this ...I'm ready to just try starting with the Otto cycle in like the second week or first week of the class, and after we do a little bit with the whole cycle. Because you've got the solved cycle with CyclePad, it can tell them what kind of process each one is. So now, we know something about how a car engine works. Let's look at these individual processes. Then we can use CyclePad to ...dissect it and look at an adiabatic process or a constant pressure process. (Interview September 1998; tape 8 p. 1)

In this way, Professor P. could take an approach that followed closer to the historical development of the field (the building of engines, followed by the discovery of the underlying theories) rather than the artificial approach of the current textbooks. Ideally, he would link this with laboratory experiments too. He would like to take these ideas and create a CyclePad-based textbook.

Unlike Professor R. who had planned the course syllabus well before the course started, Professor P. operated more on the fly. He had planned to do more with both WebCT and CyclePad, but due to bugs in the program, he had curtailed some of his plans. For example, the students did group term projects (for which, one group used CyclePad). At the end of the course, each group posted their project on the WebCT student page link. However, Professor P. had intended to do more with the shared nature of the web pages. He explained:

> What I really wanted them to do was get those web reports on there with several weeks of the semester still left so everyone in the classroom can still read them and then they'll get reviewed. Just like when you submit a paper to a journal, you'll get some reviews back and you'll be able to modify them based on their views and feedback from some other students. I sort of set it up to do that this time…but I decided that we weren't going to get there. (Interview Professor P. January 11, 1999; tape 9 p. 3)

Incremental changes

In his second year of teaching with CyclePad, Professor P. taught certain terminology earlier in the term in anticipation of the forthcoming work with the CyclePad. When modeling cycles in CyclePad, students need to know specific terminology (e.g., terms for constant temperature (isothermal), constant heat (adiabatic) and constant volume (isochoric). In observing students working with the software in both 1997 and 1998, I noticed that the students in the latter course were more proficient at using the terms in conversation (and in pronouncing them!) than the former students. Professor P. explained this change:

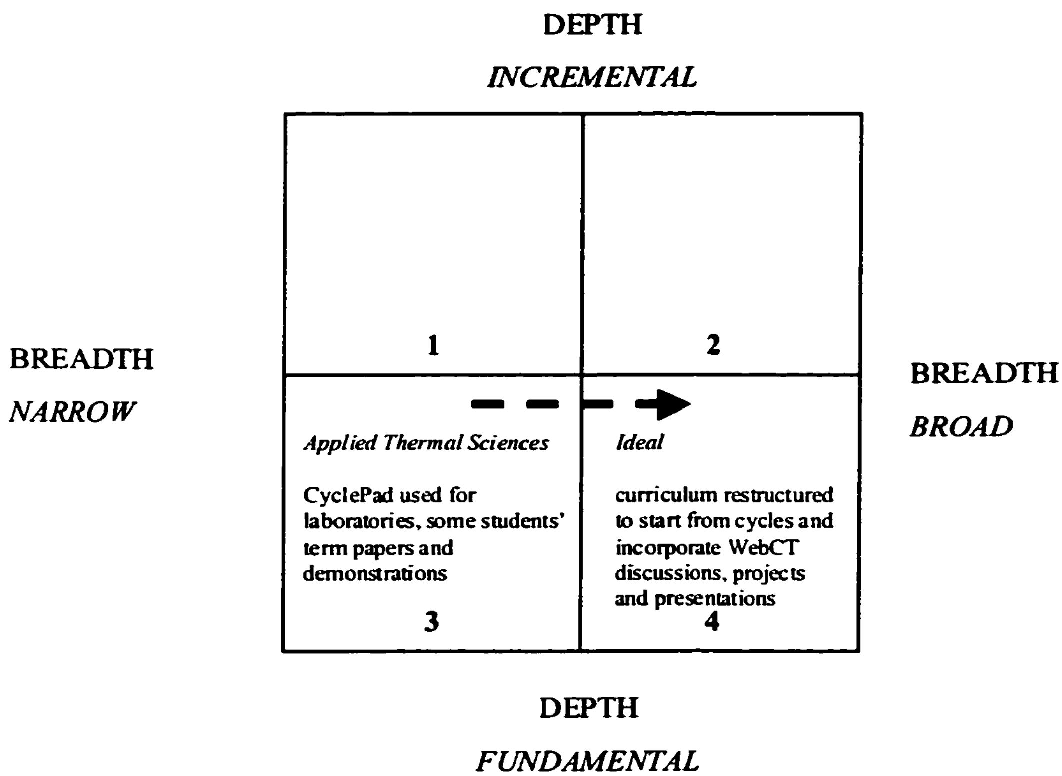
> … the first time I tried using CyclePad [1997], the semester had already started and I said, "This is great stuff!" It was all sort of done on the fly. So, this year teaching this course I had in mind to use CyclePad, so I introduced some topics quicker and some terminology quicker. So that when they started using CyclePad, they've already been exposed to some of that. (Professor P. Interview September 1998; tape 1 p. 1)

From year to year, Professor P. was developing a materials and a style of teaching that fit with his educational goals. While he had a vision of a different kind of engineering education, his was able to implement it only piece by piece.

## Summary

Of the three cases presented in this dissertation, Professor P. had the most pedagogically adventurous approach to integrating CyclePad into his course. He wrote his own problems and had students approach them using multiple methods (by hand, graphing, and in CyclePad). He thought about new, and radical, ways to restructure the course. Furthermore, he was particularly sensitive to the background of his students and tried to use the software to motivate them and compensate for their academic weaknesses. He used it as part of the students' laboratory time, combined it with WebCT to allow for discussion and linked CyclePad problems with real-world interests of the students. However, CyclePad and WebCT were only used occasionally. As shown in , this approach was fundamentally radical in its pedagogy but narrow in its curricular reach.

Figure 14: Professor P.'s "enacted" v. "ideal" teaching




In the diagram, the dashed arrow indicates the trajectory from narrow to broad curricular coverage. Professor P. intent for the future was to increase his use of CyclePad in the course by starting from cycles. He also intended to further integrate it with WebCT to develop on-line curriculum, increase student collaboration and enhance student project work. In many ways, this is the most progressive ideal of all the introductory thermodynamics courses in this study.

His ambitious teaching was limited by his lack of course planning (although WebCT seemed to provide him some structure for this that could be reused in future years), the bugs he encountered with the software and the limited departmental resources. The tension of working in a university that stresses both teaching and research presented a challenge. Yet, trying novel educational practices gave Professor P. a way to conduct research while teaching.

# CHAPTER 5

# PROFESSOR R. AT USNA

This chapter presents two contrasting examples of broad curricular CyclePad implementation: one with traditional pedagogy and one embodying progressive pedagogical practices. Interestingly, the same professor enacted these two different implementations. It was the professor's negotiation of his teaching and work context led to these two radically different styles of implementation. In one instance, he was constrained by his department and their goal of standardizing curriculum in multi-section courses. In the advanced course he taught, there was no departmental control over curriculum and thus Professor R. felt free to structure the course as he chose. Thus, the changes that Professor R. made to curricula in response to CyclePad were qualitatively different depending on the level of classroom autonomy he had.

This chapter begins with a description of the professor and his work context. This is followed by an analysis of his teaching with CyclePad in two courses and his ideal vision of teaching. The chapter concludes with a comparison of his real versus ideal teaching practice.

## Intellectual Biography

Professor R. became involved with our research group when Professor Forbus was invited by the Office of Naval Research (ONR) to speak about his research at the United States Naval Academy (USNA) in 1994. Professor R. was interested in Professor Forbus' project to develop an articulate virtual laboratory for teaching thermodynamics. This, in turn, led him to become an instructor-collaborator on the project. While the National Science Foundation (NSF) was the main source of funding for software development and educational research, the ONR provided additional funding as part of an initiative to improve teaching with high technology by linking USNA faculty with other researchers. One grant paid travel expenses between the two universities to encourage collaboration while another grant gave Professor R. summer funding to develop curriculum.

**Instructor Profile**

Professor R. received his B.S. and M.S. in Taiwan and came to the United States to attend the University of Illinois, Urbana. There he received a Ph.D. in Mechanical Engineering in 1966. As a foreign graduate student, Professor R. was disappointed that the University of Illinois did not allow him to teach although he was interested in a teaching career.

After receiving his Ph.D. he was offered jobs at several universities, he ultimately chose USNA because he did not feel that he would be successful at getting large research grants. He explained that:

> See why I came here -- the reason is -- I know I can do research but, on the other hand, I couldn't get money. The thing is, at a school like Illinois or Northwestern you've got to support lots of graduate students. You are constantly out trying to get money. That's a lot of

> pressure and I don't want that pressure. That's why I chose to come here. Although I did get offers from Columbia -- from good schools like that-- my decision was [that] I don't want to have that pressure. I'm not good at that. I can get some money but I can't get big money. (Professor R. March 22, 1999; tape 1 p. 9)

Professor R.'s teaching experience is quite extensive. In addition to his thirty-four years of teaching at USNA, he has worked part-time as a professor at the Whiting School of Engineering at Johns Hopkins University since 1968. More recently, since 1998, he has been a Graduate Faculty Special Member at the University of Maryland. As of 1999, he had no plans to retire.

## Professional Context

### University

USNA is one of four federally sponsored military academies. Founded in 1845, it offers a free education to students who will, upon graduation, serve five years in the military. The school's mission is to:

> Develop midshipmen morally, mentally and physically and to imbue them with the highest ideals of duty, honor and loyalty in order to provide graduates who are dedicated to a career of naval service and have potential for future development in mind and character to assume the highest responsibilities of command, citizenship and government.[28]

The school operates on a two-semester system – fall and spring. Faculty teach twelve hours per semester. They are required to be on campus forty hours per week, which makes them very accessible to students. With the busy teaching load and lack of graduate students, it is hard for faculty to carry out research. Their main opportunity is during the summer months (for which they often seek outside funding).

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[28] From USNA web page: http://www.nadn.navy.mil/

**Department/College**

Professor R. is appointed to the Mechanical Engineering department, which is in the Division of Engineering and Weapons. The faculty is comprised of both civilians and military personnel. Professor R. is a civilian employee.

**Course and Classroom**

This chapter describes Professor R.'s experience with two courses-- *Engineering Thermodynamics* and *Energy Conversion*. *Engineering Thermodynamics* is a required course for all engineering majors. It is taught in twenty sections per year to approximately four hundred students. There are no teaching assistants so faculty members are responsible for all interactions with students and grading. *Engineering Thermodynamics* is a matched multi-section course, which means that it is standardized across the different instructors and sections by sharing the same textbook and final exams. As I will describe later, the departmental standardization becomes an obstacle to curricular experimentation.

Professor R. also teaches CyclePad in *Energy Conversion*. Unlike *Engineering Thermodynamics*, this course is offered in one section in the spring term. The objectives of the course are "(a) development of basic analysis and design of energy conversion devices; (b) application of basic mechanical engineering to energy generating systems."[29] In this course, students are assigned four short projects and one longer-term project. CyclePad was used in some of the short projects and for the term project in which students are asked to design energy devices.

For both courses, Professor R.'s lectures were held in a standard classroom with rows of desks and a blackboard in the front of the room. In his first years using CyclePad, Professor R. had to wheel a cart with computer and projector into the classroom to do demonstrations. Students had access to CyclePad in a computer laboratory where, in the first few years of this study, there were only nine Pentium computers that were fast enough to run CyclePad. This meant that students had to share computers and work in groups. By 1999, the

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[29] From Energy Conversion Syllabus Spring 1999

computer classroom was better equipped with more computers that were faster. This allowed students to work alone. Furthermore, an overhead projector device had been installed so Professor R. could do demonstrations in the same space as students work on individual computers.

**Students**

USNA's approximately 4,000 undergraduate students represent all fifty states and more than a dozen foreign countries. To apply to the academy, students must be sponsored by their state representative or other government official. Students must enter the program as plebes (freshman). The academy recommends SAT-I scores of at least 530-verbal and 600-math. A majority of the students admitted come from the top 20% of their high school class. Students must also pass a medical exam, have 20/20 uncorrected vision and take a physical exam (300-yard run, long jump, etc). The U.S. government pays full tuition for students. There are no graduate students. Every entering midshipman (equivalent of a freshman) receives a computer for his or her dorm room.

The student body is overwhelmingly male (84%) and 20% minority (Asian or Pacific Islander, Hispanic, black, native American, international). Forty-four percent of the students major in engineering. In the classes that I observed, all the students were engineering majors and there were usually only one or two female students per section.

## Teaching with CyclePad

In this section I focus on Professor R.'s implementation of CyclePad in each course. This is followed by a discussion of his ideal usage and an analysis of the obstacles he encountered in trying to reach his goals.

### CyclePad in *Engineering Thermodynamics*

Professor R. saw CyclePad as serving two functions for students in the introductory thermodynamics course: (1) acting as an extra instructor and (2) providing students answers to homework problems in cases where answers were not printed in the textbook. For this course and audience, he conceived of CyclePad as a teaching assistant rather than as, for example, a simulation or research tool. He explained this view of the tool and his students' needs:

> [The students] are using [CyclePad] for two purposes. One is an extra instruction device. You see, many students come here, they don't really have a problem with the concepts, but they have problems working out the problems. ... they understand but they don't know how to work them out. CyclePad will give us that so they don't need to see me -- CyclePad can answer their questions. And then I have them use it to double-check their homework. You see, many of the homework problems do not have solution answers and the students complain that "I don't know if I'm doing it right or wrong. I'm not sure." So they can use CyclePad. (Interview March 22, 1999; tape 2 p. 5)

Professor R.'s *Engineering Thermodynamics* CyclePad Curriculum

Professor R.'s curriculum development was tied to the content of the students' textbook. As course coordinator for the *Engineering Thermodynamics* in the 1996-97 school year, Professor R. developed a version of the standard curriculum that included a CyclePad option. He distributed two versions of the syllabus to the course instructors, one with CyclePad and one without. Included in the CyclePad syllabus was a list of what problems to demonstrate to students and which to assign as homework problems (to be done both by hand and with CyclePad). That year Professor R. and a new hire -- Professor G. -- used the CyclePad version of the syllabus.

By 1999, Professor R. had expanded the content coverage of his CyclePad problems from cycles to include "pre-cycles" (analysis of individual processes and components). Whereas in previous years, CyclePad was first introduced when cycles were taught, the addition of certain features in the newer versions of the software allowed for CyclePad to be used to easily analyze single processes. Professor R. took advantage of this new feature to introduce CyclePad earlier in the term for these very simple single component problems. He continued to assign problems to be done both by hand and by CyclePad. In doing so, the degree of curricular integration of CyclePad increased over the years so that its implementation spanned most of the course.

Throughout his usage of CyclePad in this course, Professor R. did not write his own problems but assigned textbook problems. The textbook problems are typically of a word problem format that gives some initial conditions for a system and asks the students to calculate a parameter or two. The problems selected for CyclePad usage all required numeric answers. Professor R. tested the problems himself before assigning them to make sure that they were solvable in CyclePad (i.e., they could be modeled in the software and did not run into any bugs). Each year he selected new problems to prevent students from cheating by referring to past answers and because sometimes the department would change the textbook. Thus, curriculum development time consisted of selecting problems from each chapter in the textbook and trying them out in CyclePad to pick those that were solvable. Using standard textbook problems fit Professor W's view of CyclePad as a means for instructional aid, rather than as a means for pedagogical reform.

Instructional Strategies

In order to achieve his goal that students consult CyclePad as an extra instructional device, Professor R. spent class time teaching students how to solve textbook problems in the software. During my visits between 1997 and 1999, I observed that Professor R. took a similar approach to teaching students this skill. Initially, he would demonstrate it himself by using the projector to show students the steps he would take in solving a problem. After the demonstration, students would work in-class on several assigned. While they did this, he circulated around the classroom to answer questions or provide instruction on problem solving.

Professor R. had a consistent methodology that he followed when demonstrating to students how to solve the textbook problems. He usually specified the state points (i.e., conditions of the inlet and outlet of a component) before making modeling assumptions about the component itself. He always proceeded in an orderly fashion by moving from left to right in a process diagram or clockwise around a cycle. His explanations to students of how to do various functions in the software had little variety. While there are several ways to accomplish the same task or result in CyclePad, Professor R. usually stuck to one pathway. For example, Table 15, a representative teaching vignette, shows Professor R.'s demonstration of how to solve a refrigeration cycle problem. In the transcript, I have underlined the meta-questions that Professor R. used to guide students through the solution process. In the second column, I have labeled the instructional steps. Figure 15 illustrates the cycle that Professor R. is constructing in CyclePad during this teaching episode.

In this teaching excerpt, Professor R. is explaining how to solve the following problem in CyclePad:

> Example 10-1: The Ideal Vapor Compression Refrigeration Cycle
>
> A refrigerator uses refigerant-134a as the working fluid and operates on an ideal vapor-compression refrigeration cycle between 0.14 and 0.8 MPa. If the mass flow rate of the refrigerant is 0.5 kg/s, determine (a) the rate of heat removal from the refrigerated space

and the power input to the compressor, (b) the rate of heat rejection to the environment, and (c) the COP of the refrigerator. (Cengel, 1998, p. 621-622)

Figure 15: Refrigeration Cycle built in CyclePad

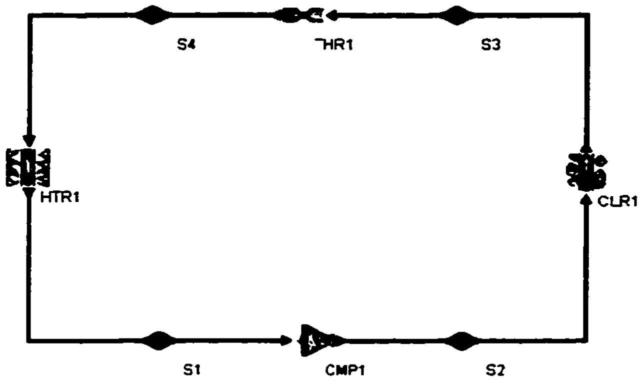

Table 15: Teaching vignette[30]

| Transcript | | Instructional Step |
|---|---|---|
| Prof. R.: | Lets start with 10.1 Read the problem. And let me show you how to do one problem and then from there on you should be able to do the others. | read problem specification |
| Prof. R.:<br>STUDENTS:<br>Prof. R.: | 10.1 is a refrigerator. And a refrigerator is a closed cycle or an open system?<br>Open<br>So you see we have open here [indicating the open choice on the new cycle dialog] and we have open cycle steady state. So we say okay. [clicks "OK"] | determine whether cycle is an open or closed system |
| Prof. R.: | ...the basic refrigeration cycle is made by four components. The components are: compressors, so you take a compressor out, then you have a cooler, so you take a cooler out, and then you have throttling valve so you take one out. [he takes each out as he mentions them]. ...Other than that we also have an evaporator, which is a heater, so take a heater out. | select the appropriate components |
| Prof. R.: | And we simply connect them....[he connects the components] | connect components |
| Prof. R.: | So now you click on the mode and go to analysis mode. [the "switch to analyze" dialog comes up and he picks "analyze"] So first you build and then you click on the mode and you analyze it. | switch to analyze mode |
| Prof. R.:<br>STUDENT1:<br>Prof. R.: | Alright. ... what is the working fluid?<br>Refrigerant 134.<br>So we go here [clicks on a state point]. You ... select a substance -- refrigerant 134a. | select stuff for system |
| Prof. R.:<br>STUDENT2: | What are the given conditions?<br>[reading from his textbook] It says it operates on an ideal vapor compression refrigeration cycle between .14 and .8 megapascals. | re-read given conditions and start entering values at an appropriate state |

[30] From classroom observation April 21, 1999 transcript pages 1-2

| Transcript | | Instructional Step |
|---|---|---|
| Prof. R.: | Okay, so maybe you can start with the inlet of the compressor. So this is your inlet of the compressor so click on that. [he opens the state point to the left of the compressor icon] ... you see that you know two properties of state 1. What are the two properties? | point |
| STUDENT4: | Pressure and quality. | |
| Prof. R.: | ... first of all you go to "phase" and you select a phase that is "saturated." And the quality ? | |
| STUDENT4: | Zero. | |
| Prof. R.: | Zero or 100? One isn't it? The quality is one, isn't it? Right? [He enters "1" for quality].<br>So now you have one property in. The other property --you know the pressure. What is the pressure? | |
| STUDENT5: | .14 megapascals | |
| Prof. R.: | .14 megapascals or 140 kilopascals. So you put in 140. [He enters "140" for the pressure at state 1.] Whatever I put in is in green and the computer ...will calculate everything in blue. So this state is defined. | illustration of the state postulate |
| Prof. R.: | So let's go to the outlet. What do I know? I know the pressure so we assume a value and the pressure is 800 kilopascals. [He enters "800" for the pressure at state 2.] | specify information for remaining state points |
| Prof. R.: | I need another property, don't I? So now lets click on the compressor and we define what process we have. What process do we have? | enter modeling assumptions |
| STUDENTS: | Isentropic. | |
| Prof. R.: | Right isentropic. So we make an assumption, we say it works adiabatically. If it works adiabatically what would be the efficiency? 100 -- isn't it?...Adiabatic and 100% efficiency is isentropic. ... Now what is the process for cooler? ... [He continues to input values for the remaining state points and components.] | |
| Prof. R.: | You have to know the cycle. The cycle is made by several process. You have to define each process. ... [He picks T-s diagram from the "cycle" menu] Here's your T-s diagram. Okay? Then we can also see the cycle properties [He picks "whole cycle property."] | check that cycle is "solved" by viewing T-s diagram and cycle properties |

Professor R. was very consistent in his teaching strategy. This pattern was noted in the two sections of *Engineering Thermodynamics* he taught. In fact, there was little variation in his script between the two sections. This pattern was also noted on other days and in sections during other academic terms. Professor R. had been teaching this course for 33 years. He did it from memory, with no lecture notes. His rote approach had been honed over the years to a simple style of presenting to the students the minimal amount of information needed and a single methodology to solve thermodynamics problems. Using the problem solving steps he presented, a student could potentially solve any problem using CyclePad.

### Student Learning

Since Professor R. was the only professor in the matched section *Engineering Thermodynamics* courses using CyclePad it would be evident if his section was not performing as well as the others. Professor R. worried that perhaps students were relying on the software to get answers and not spending enough time learning how to solve problems by hand. He realized that he had to scale back CyclePad usage from what he would ideally like to do, otherwise, it would "disadvantage" his students on the exams. He did not want CyclePad interfere with the learning necessary to perform well on the shared course assessments. In this way, the standardization of assessment practices enacted by the department and concerns about student achievement had the effect of limiting Professor R.'s implementation of CyclePad.

## Student Motivation

Professor R. was well aware of the students' heavy course load, athletic requirements and military responsibilities. The consequence of which is that students have little free time to devote to their studies and often look for short cuts.[31] Students were not required to submit the CyclePad problems for grading. This resulted in few students bothering to use CyclePad to check

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[31] Unfortunately, several years ago, this led to a cheating scandal at the academy that attracted national attention. In efforts to discourage future cheating, the department switches textbooks every three years, and makes changes to the homework problems yearly so that students cannot resort to files of previous years' homework and exams.

homework answers and unfortunately undermined the learning goals he had for his students regarding CyclePad usage.

Another problem, which Professor R. encountered, was that the students are trained to respond to direct commands and not to take individual action. This is a major part of the culture of a military school. For example, when we discussed whether the *Engineering Thermodynamics* students were using CyclePad to check their homework problems Professor R. explained to me that the students only do what is required of them:

Researcher: Do the students tell you that they check [homework problems] sometimes?

Prof. R.: If you don't force them, they don't do it.

Researcher: They don't bother?

Prof. R.: They don't. They don't have time. One of the first premises of USNA-- If you tell them to do it, they do it. If you don't -- I doubt many students actually use CyclePad to their advantage. But, I told them to use

> it if they want. Now, at another school, I'm not sure whether that's the case or not. But here -- it's a special school. You don't blame the students because that's the way the system works. If the authority tells them to do something then they do it. That's fine. If the authorities don't tell them to do it and they do it and something is wrong, then they are the ones to blame because they were not approved to do such things. (Interview March 22, 1999; tape 2 p. 5-6)

Professor R. seemed understanding of the fact that many students were not using CyclePad and saw it as stemming from the culture of the college rather than student reaction to the software itself. In Professor R. interpretation of the students' school context, the pressures on their schedules and the goals of military training come into conflict with certain educational practices such as "optional" class work. In this way, the students and their school environment played a role in shaping Professor R.'s enactment of CyclePad.

## <u>CyclePad in *Energy Conversion*</u>

In *Energy Conversion,* Professor R. saw CyclePad as expanding what students were able to do. It let them work on advanced and complicated assignment and design problems. In contrast, where CyclePad was a required part of the *Energy Conversion* students did find time to use the CyclePad. Professor R. felt that CyclePad could help students vary parameters and optimize and design systems. He wrote in a journal article (Wu, 1999; p. 236):

> In the realm of thermodynamics, CyclePad is to a mechanical engineer what a word processor is to a journalist. The benefits of using this software for teaching and design purposes are numerous. First, significantly less time will be spent doing numerical analysis. Computational work that would have taken hours before can now be done in seconds. Second,...CyclePad is capable of analyzing multi-cycle systems with various working fluids. Third, due to its computer-assisted modeling capabilities, the software allows for individuals to immediately view the effects

> of varying parameters, either through calculated results or in the form of graphs and diagrams, giving the student a greater appreciation of how a system actually works. More specifically, there is feature that provides the user the opportunity to optimize a specified cycle parameter.... Last, and probably most important, there is a built-in coaching facility. CyclePad goes a step further by informing the user if a contradiction or an incompatibility between input parameters exists within a cycle and why.

## Professor W's *Energy Conversion* CyclePad Curriculum

In contrast with *Engineering Thermodynamics*, Professor R. did not use a textbook in *Energy Conversion*. Instead, students read journal articles, and worked on several short projects and a longer-term project. Professor R. integrated CyclePad into both class time (during which students used the software to model complex cycles) and as a homework tool to use for the term project. Professor R. would create a list of possible term paper topics for the students to choose by selecting projects for which CyclePad could be used to model the system. The list of projects would provide students with reference information to read about the cycles in the projects. Professor R. would have liked to integrated CyclePad into more of the short projects in the course; however, the software was limited in the types of fluids it modeled.

For this course, Professor R. primarily used CyclePad as a research tool for students to explore and design cycles. This is a different conceptualization of the software than that he had for *Engineering Thermodynamics* where CyclePad was intended to be an instructional resource. Professor R. had, himself, been using CyclePad as part of his research (e.g., (Wu, 1999)). He had his advanced students reproduce the results of one of his papers as a homework assignment. The students also used CyclePad as part of their term projects in which they analyzed various cycles. Two of these papers went on to become journal publications (Wu & Burke, 1998; Wu & Dieguez, 1998). Professor R.'s use of CyclePad represents a very innovative blending of research and teaching. This "scholarship of research and teaching" is one of the key areas of exploration in higher education reform. Many researchers believe that teaching and research can be improved by bringing them closer together

(Boyer, 1990)[Hutchings, 1999 #280]. This provides, perhaps, one example of how to link research and teaching in engineering education.

**Professor R.'s Ideal of Teaching with CyclePad**

Professor R. wanted to use CyclePad in *Engineering Thermodynamics* in a way that he described as "totally immersed." To him, "immersed" means using CyclePad not just for cycles, but also from the beginning of the course. However, due to the standardization of *Engineering Thermodynamics* across sections, Professor R. was constrained in what he was actually able to do in the CyclePad-sections of the course. Therefore he requested funding to develop an "experimental" section. In a letter to the Office of Naval Research (ONR), he wrote:

> I have experienced several constraints to using CyclePad to its full potential in teaching thermodynamics classes the last two years. To integrate CyclePad into the thermodynamics courses at U.S. Naval Academy more extensively and efficiently, I would like to create a fully immersed CyclePad experimental section of thermodynamics

> in which the software would be presented to the students in the course very early and innovative problems could be studied. I hope this approach will help students better understand concepts. (December 4, 1997, letter to ONR)

He wanted to use an experimental section to address problem with assessment. He explained that:

> Several students in [Engineering Thermodynamics] said why should we bother using CyclePad if we cannot use it in exam. They had a point. It is a good point. Why should we bother to learn that? [He chuckles.] (March 22, 1999 Interview; tape 2 p. 10)

His "immersed" CyclePad section would allow students to use the software on exams (this would also get around the shared exam that is currently in-place and allows for comparison of his section with other instructors). He would also do more in-class examples of CyclePad problems and almost all homework problems would be done in CyclePad.

The ONR funded Professor R. in the summer of 1998 to develop the curriculum for an experimental section of *Engineering Thermodynamics* to be taught in fall of 1998. Professor R. ended up taking a sabbatical in the fall, so he planned to teach the course the following spring. However, he ran into opposition when he asked the department for permission to run the experimental section. The department chairman rejected the idea because the students would not be able to use CyclePad on the Engineer-in-Training (EIT) exam. Furthermore, other instructors voiced their dissent and concerns about CyclePad. Professor R. related their issues:

> The instructors are against [me using CyclePad] because they feel that if they use too much CyclePad the students would have lost the ability to do problems by hand. And that's to their disadvantage. Particularly on the EIT exam or Professional Engineering exam where you won't have those things for them and you have to do them by hand. So many concerns are like that." (Interview March 22, 1999; tape 1 p. 1-2).

In contrast, Professor R. was able to teach *Energy Conversion* with CyclePad in an almost "ideal" fashion. He could assign whatever projects he wanted to and determine how and when students used CyclePad. There were no departmental constraints on either the content of the course or the use of software. The only limitations, which he encountered, were those posed by the software itself.

**Ideal Software: Viewing fundamental equations**

One of the weaknesses Professor R. identified in using CyclePad to solve textbook problems was that he felt it did not make the link clear between the fundamental thermodynamic equations and Cycle Pad's problem solution. One of Professor R.'s ideas for improving CyclePad was to give instructors an option of displaying the three governing equations (first law, second law, and continuity) in the software. He wanted students to be able to see how what they input in CyclePad was used in solving the equations. He explained his rationale for this:

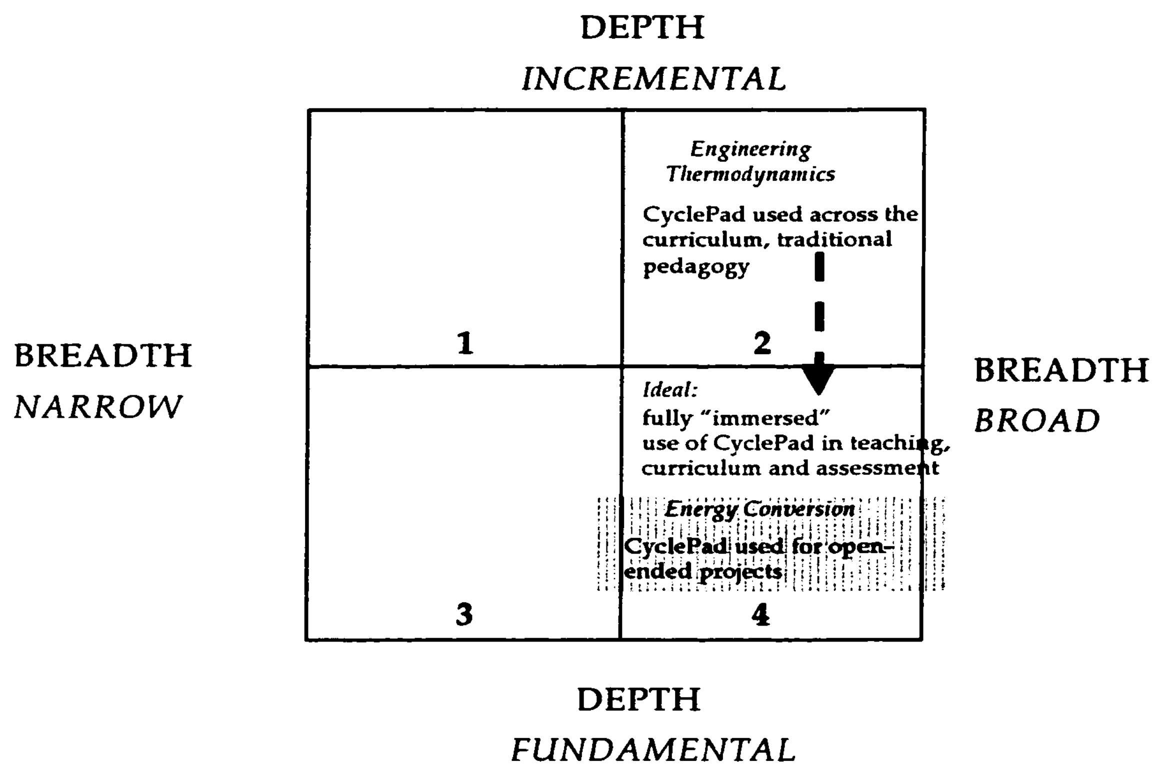
> What we do in classroom teaching [is that] we show the cycle and we show the system and then we tell the students how to solve it by using this equation or that equation or a combination of equations and then again input values in CyclePad ... you define a process, input values in and here comes the output. But it doesn't have the equations. So that's what we need. That would be advantageous for CyclePad to be used in first level - for [Engineering Thermodynamics]. That is necessary. But for the [Energy Conversion] students it's not necessary because they already know that. ... (Interview March 22, 1999; tape #2 p. 13)

While Professor R. was aware that the software's explanation system could be used to display equations, he apparently did not feel that this was adequate for instructional purposes. He felt very strongly that there were only three governing equations that students needed to focus on and that that was all that needed to be displayed. The explanation system shows many different equations in several different forms (depending on what variables are known).

## Course Comparison: What was versus what could be

Professor R. integrated CyclePad across the breadth of the introductory thermodynamics curriculum, however, with only incremental changes in teaching (as shown in , quadrant 2). In his Energy Conversion course, his use of CyclePad led to fundamental instructional change by engaging students in open-ended problem solving and linking their studies with research (see quadrant 4).

Figure 16: Professor R.'s "enacted" v. "ideal" teaching




Professor R.'s ideal introductory thermodynamics course while broad in curricular coverage used a traditional pedagogy. The dashed arrow in shows the trajectory to the "immersed" CyclePad course. In this ideal, students would do almost all their work in CyclePad and use the software on exams. While by 1999 he had managed to integrate CyclePad across the curriculum of *Engineering Thermodynamics*, he was not allowed to make it a required part of the course or to have students use it on exams. Several factors make this a difficult change to envision. First, there is the problem of the department's goal of standardizing the *Engineering Thermodynamics* sections. This does not allow for individual professors to alter the curriculum. Second, there is the problem of the military student culture. The "gentleman's C" is an acceptable level of achievement. Since students are required to graduate in four years they must make passing grades in all their courses. This combined with their busy schedules of athletics, academics and military training, acts to lower students' academic standards. As Professor R. pointed out, students would do what was asked of them, but they would not do what was optional. Therefore, Professor R.'s optional use of CyclePad in *Engineering Thermodynamics* did little to engage students in using the software.

In *Energy Conversion*, Professor R. had students use CyclePad as a research tool for projects. Since he was the only instructor for the course, he had the latitude to structure and teach it in any way he wanted. In this course, he demonstrated a more ambitious pedagogy that linked learning, teaching and research. In this course, Professor R. did not follow a textbook and thus made up his own curriculum, which consisted of several short projects and one longer term paper. Students used CyclePad for some projects and the term paper analysis of an energy system. Professor R. linked CyclePad usage to his research articles, and, as mentioned earlier, two of the student term papers were published in research journals. In this way, *Energy Conversion* was pedagogically ambitious throughout the breadth of the curriculum.

The differences in teaching between the two courses is perhaps similar to that found by Spillane (1995) who examined a public school teacher's teaching of two different subject areas. He found that the teacher showed ambitious pedagogy in language arts while teaching mathematics traditionally. In this case, Professor R. was teaching two courses within the same domain of mechanical engineering, yet the degree to which he was able to innovate with

CyclePad was quite different. In interacting within his work context, Professor R. conceptualized it differently for E*ngineering Thermodynamics* than for *Energy Conversion*. His dual uses of CyclePad (as a teaching tool in the introductory course versus as a research tool in the advanced course) and his views on student motivation and his reaction to departmental constraints factored into his construction of the curriculum and the ensuing enactment. This case provides evidence that the teaching practices of one individual may vary even *within* a domain. If we look only at one course, it may not necessarily be indicative of an instructor's teaching capacity. The instructor's negotiation of his work environment -- from the classroom and curriculum level up through departments to national professional exams – factor into the style and development of teaching practice at the classroom level.

# CHAPTER 6

## INSTRUCTOR O. AT NWU

This case describes the usage of CyclePad in two courses at Northwestern University (NWU). The implementations were quite different; one reached broad curricular integration yet with limited pedagogical impact. In the other course, CyclePad was implemented with a fundamentally different pedagogy, however, limited to one a small slice of the course. One of the factors that makes this case unique, compared with the preceding two, is that the CyclePad instructor's actions were the results of negotiations with the courses' regular professor regarding allotment of time, choice of activities and content coverage. Instructor O.'s role was only to teach about CyclePad but not to teach the other lectures in the course. This framed how he viewed the possibility of his role in the classroom and the extent of his curriculum development activities. His inability to impact both pedagogy and curriculum limited the outcome of Instructor O.'s work so that neither course had a both broad curricular change with a fundamentally revised pedagogical approach.

Unlike the previous two cases, at NWU there was a team of researchers, in addition to the actual instructor, involved in the planning and implementation of the CyclePad interventions at this site. The team consisted of computer science graduate students, programmers, a learning science graduate student (me) and a mechanical engineering graduate student (Instructor O.). In the early years of classroom interventions, one of the computer science students, G. acted as CyclePad instructor. By 1997, he had graduated and left NWU. The research for this dissertation begins at the point where Instructor O. had assumed the role of CyclePad intervention instructor.[32]

This chapter begins with a description of the professor and his work context. This is followed by an analysis of his teaching with CyclePad as a guest lecturer in two courses and his ideal vision of teaching. The chapter concludes with a comparison of his enacted versus ideal teaching.

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[32] In this chapter, I refer to O. as an "instructor" rather than "professor" as he was not appointed to the faculty of NWU.

**Instructor Profile**

Instructor O. taught the CyclePad interventions from 96/97 to the present (99/00) school year. During this time, Instructor O. was completing his mechanical engineering Ph.D. He had joined the research group as a subject matter expert to aid in the creation and testing of Cycle Pad's knowledge base. With G.'s departure, Instructor O. became involved more directly in the classroom research. I worked closely with Instructor O. on the design of curriculum from a pedagogical perspective while O. contributed his expertise in the subject matter and knowledge of the engineering students that he had gained from his experiences at a teaching assistant.

As an undergraduate, Instructor O. had chosen to study engineering at California Polytechnic State University (CalPoly) because it was more hands-on than the other engineering programs he was considering. He described the difference he perceived between NWU and CalPoly:

> Northwestern isn't known for being a hands-on school whereas Cal Poly, at least when I was there, their whole ad campaign to get

> engineers was that you leave this school and get hired by Hewlett Packard and you know how to use a spectrum analyzer. So part of the reasons students went there, part of the reason I went there, -- as opposed to Berkeley -- is that I'd have real skills when I leave. (Instructor O. interview 7-28-99; tape1 p. 6)

O.'s prior instructional experiences included being a teaching assistant and tutor for engineering courses. He had been a teaching assistant for *Thermodynamics II* in 1997. In comparing his own experience as a student in thermodynamics to that which he saw at NWU. He noted that NWU thermodynamics courses did not have any laboratory sections associated with them. He felt that NWU was not as hands-on of an engineering program than what he had experienced at CalPoly. He explained:

> [My education] was not different in how the lectures were run, but were very different in how the labs were connected. You'd get into the lab and run experiments every week and spend three hours

> doing this and it really helped you out if you knew the concepts. (Instructor O. interview 7-28-99; tape1 p. 5)

His experiences with laboratory thermodynamics helped him to understand how to apply the principles learned in class to real-world engineering problems.

## Professional Context

### University

Founded in 1851, NWU is a private research university school with approximately 15,000 students (~ 7,600 undergraduates) and over 2,100 full-time faculty members. The main campus is located in 231 acres in a neighboring suburb of Chicago. Classes are offered on a quarter system (fall, winter, and spring). Northwestern is a highly selective university where, for example, eighty-seven percent of the class who entered in the fall of 1998 had graduated in the top ten percent of their high school class. While valuing teaching, research also plays a major role in the school's mission:

> The research program at Northwestern is a major component of University efforts, assuring institutional leadership in scientific discovery, intellectual inquiry, and creative performance. The character of this research shapes all areas of University endeavor, especially graduate education as well as undergraduate studies...[33]

Thus, like many other elite research universities, the focus in on professors doing research, rather than on exemplary teaching. At schools such as UALR and USNA, the teaching of students is a top priority. While professors there are still expected to do research, there are fewer institutional supports.

**Department and Collaborators**

Two mechanical engineering professors, L. and T., collaborated on the NSF grant by allowing CyclePad to be used in their thermodynamics courses. Both were tenured faculty members with many years' experience in teaching

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[33] From http://www.nwu.edu/factbook/factbook99/facts4.html

thermodynamics[34]. They were given several demonstrations of the software as well as a computer on which to use the program. However, although they were willing to try CyclePad in their class, over the years neither learned much about how to operate the software themselves. This is perhaps one reason why they never took over as instructors in the CyclePad interventions and were happy to let Instructor O. lead that part of the class. In fact, Professor L. wrote:

> CyclePad is an interesting application of computers in a learning environment. I had the great advantage of having Instructor O. on hand to completely run the CyclePad portion of the course. He developed CyclePad problems directly from the text (Cengel & Boles). This gave me the opportunity to present those problems to the class as [the students] were also working them using CyclePad. Would I have used CyclePad if Instructor O. did not participate? I

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[34] Unlike the professors in the previous two case studies, NWU faculty who are active in research teach fewer courses per term. Those at NWU who are not actively doing research may be teaching two or three courses a term.

doubt it. But, if I were a younger faculty member preparing a set of notes for a thermo class and working toward tenure I might consider CyclePad as an effective adjunct to my teaching duties ... Professor L. from survey October 25, 1999)

**Course and Classroom**

For this dissertation, I followed Instructor O.'s teaching in Professor T.'s *Thermodynamics II* and in two sections of Professor L.'s *Thermodynamics I*. *Thermodynamics I* covers the first half (through Carnot cycles) of the Cengel and Boles' (1998) Thermodynamics: An Engineering Approach. There was no pedagogical reason for not covering more types of cycles in the first course; it was an artifact of NWU's 10-week quarter system that the cycle chapter was covered in the second course. At other schools, such as USNA, cycles are taught at the end of the first course. *Thermodynamics II* covers the second half of Van Wylen and Sonntag's (1994) Fundamentals of Classical Thermodynamics including the chapters on specific cycles (e.g., Otto, Diesel, Rankine, etc.).

All courses met in a regular classroom (rows of desks with blackboard in front). For some of our CyclePad interventions, the class met in one of the computer laboratory "smart classrooms" in the engineering building. The computer laboratory had a workstation at every student's desk and an overhead projector that allowed the instructor to project his computer display onto the front wall. At other times, a portable projector and a laptop computer were brought to the regular classroom in order to present demonstrations with CyclePad.

## Students

During this study, *Thermodynamics II* had approximately 30-40 students enrolled. *Thermodynamics I,* which is offered in several sections each quarter, had approximately 10-15 students per section. There were more men than women in the courses (women represented under 25% of these classes). The students in *Thermodynamics I* were mostly sophomores (75%); approximately half were mechanical engineering majors. The other half of the students represented the full spectrum of engineering disciplines (e.g., industrial, civil, biomechanical, electrical, and computer science). The *Thermodynamics II* students were all mechanical engineering students, the majority of whom were in their senior year.

## Teaching with CyclePad

In this section, I discuss Instructor O. and the research groups' goals for implementing CyclePad in thermodynamics courses, the curricula we developed for the two NWU courses and the enactment of the curricula.

### Educational Goal: Conceptual Understanding

One important goal for using CyclePad in teaching thermodynamics was to increase students' conceptual understanding of the domain. By automating the mundane aspects of problem solving, we hoped that CyclePad would allow students to focus on design strategies. In thermodynamics, this requires making several simplifying modeling assumptions about the system that will ultimately allow application of specific formulas to calculate numeric values. While most textbook problems embody both aspects – making modeling assumptions and performing equation manipulation and calculations, we felt that the former (i.e., modeling) was where conceptual understanding is exhibited. Instructor O. explained:

> [While] there is some talent required to getting numerical answers; I think our assumption is that ultimately all that cleverness is in making the assumptions. If you make the assumptions and you are fastidious about keeping the equations in line, then you will get the right answers [whether] doing it by hand or doing it in CyclePad. It turns out, that when you do it by hand there's a lot more grinding to do but you're not being anymore clever doing the grinding -- you're just doing the grinding - plugging three different numbers into a complicated equation to get another answer out. It's more work but you haven't learned anything more. (Interview with Instructor O. 7/28/99; tape 2 p. 6)

Instructor O. discussed problem solving as being a shift away from formula manipulation and towards conceptual understanding. Since students using CyclePad did not need to derive equations and calculate values, he felt that students could focus on making the modeling assumptions and examining the consequences of their assumptions (e.g., answering questions such as: Why does the efficiency equal a certain value? Why does the dryness of the turbine outlet vary with the mass-flow?). Instructor O. explained:

> In theory, none of the things that CyclePad makes easy for you are things that you really want the students to have to know. Like they shouldn't really know how to derive from the first law to some tiny equation. It's just making the assumptions that is important... What changes is that it becomes key to ask the questions -- the "why" questions. That's just not a part of the traditional coursework. (Interview with Instructor O. 7/28/99; tape 2 p. 3)

As described below, one of our goals became to use CyclePad to bring these "why" questions into the thermodynamics curriculum.

## CyclePad in *Thermodynamics I*

From our work with other professors, we realized that CyclePad could be used in introductory thermodynamics if several modifications were made. By adding features to the closed-cycle design interface, students could now use the software to analyze individual processes. This was key to integrating CyclePad with the content and approach used in the first chapters of most thermodynamics textbooks.

By Spring quarter '99, we were ready to try the new version of CyclePad with students in *Thermodynamics I.* Professor L. was willing to let us integrate CyclePad into his two sections of the course. We had learned from our experiences in *Thermodynamics II,* as well as from the experiences of schools such as USNA and UALR, that the CyclePad intervention would be most successful if perceived by students as a part of regular course work. We had come to realize that CyclePad had embedded in it an assumption that users had a base-level understanding of thermodynamics. Therefore, we saw it as a challenge to teach novices how to use the software while they were learning thermodynamics. We then created a series of design exercises that supported the growth of both their knowledge of the software and the subject matter.

To integrate the CyclePad curriculum into the course, Instructor O. proposed several ways in which he could participate. He explained:

> I do see perhaps three areas where there are worthwhile ways to integrate the software into the curriculum.
>
> First, I think it would be beneficial to the students to have several sessions where they meet in MG45, the computer lab, and give them a hands-on introduction to CyclePad and assist them in using it to help solve some problems. I estimate that meeting four times (perhaps on alternating homework days starting the second week) would be enough.
>
> Second, where there is an appropriate opportunity to modify a book problem so that it may be an illustrative CyclePad problem, I would like to do that. I think this would alter about two homework problems per week.

> Third, there may be a good opportunity to give students a jump-start on thermodynamic cycles by modifying the last week's scheduled lectures to introduce the basic cycles. Professor T. begins the [Thermodynamics II] course with the Van Wylen chapter on irreversibility, availability, et cetera, so the students would not necessarily miss that material. (From e-mail 2/12/99 Instructor O. to Professor L.)

This, in fact, became the plan for the Spring '99 CyclePad intervention. As shown below in Figure 17, there were six CyclePad lectures. For hands-on work, the class met in the computer lab. For his lectures, Instructor O. brought a projector to the regular classroom to demonstrate CyclePad. Students submitted homework and questions through Cycle Pad's e-mail system. However, they also used class time to ask questions. We used the final week of the course to have students try cycle design problems. Instructor O. and I only attended class when he was teaching except in one instance in the last week of the term when the professor was teaching about cycles. We attended that class to ensure that what we prepared for the students matched their final lectures. This was not necessary during the rest of the term as Professor L. was following the textbook sequentially.

Figure 17: *Thermodynamics I* syllabus 1999

| | | |
|---|---|---|
| 01. 03/29 | §1.1-1.3 | Thermodynamics; energy; basic ideas |
| 02. | §1.4 -1.8 | Energy forms; properties; state; processes; the state postulate |
| 03. | §1.9-1.10 | Pressure and temperature |
| 04. | Problems(1): | 1-10E, **12**, 43, **46**, 53E, 77, **82** & CyclePad Introduction |
| 05. 04/05 | §2.1-2.3 | Pure substances; phases; phase change |
| 06. | §2.4-2.5 | Property diagrams; vapor pressure |
| 07. | CP & §2.6 | Property tables; process vs equation of state, CyclePad demonstration |
| 08. | Problems(2): | 2-**26**, 29,34E, 44, **CP1**, 52, **CP2**, **74**, 84, **99**, 104, |
| 09. 04/12 | §2.7 | Ideal gas |
| 10. | §3.1-3.4 | Heat and work; polytropic processes |
| 11. | §3.4 | Continued |
| 12. | §3.5 | The First Law of Thermodynamics |
| 13. 04/19 | §3.7-3.8 | The free expansion; specific heats, CyclePad demonstration |
| 14. | Problems(3): | 3-**18**, 22, **23**, **CP3**, 38, 44E, **CP4**, 57, 64, 69, 74, 77, 83, 86, **102**, 105 |
| 15. | Problems(3): | 3-**117**, **161**, 168, 180 |
| 16. | §4.1-4.2 | First Law for control volumes (open systems) |
| 17. 04/26 | §4.3 | Examples of open system problems, CyclePad demonstration |
| 18. | | Detailed discussion of heat engines and heat pumps |
| **19. 04/28 Wed** | | **1st Mid-term exam: Chapts. 1,2,3 ** (6:30pm) **** |
| 20. | Problems(4): | 4-11, **16**, 22, **CP5**, 32, **33**, 45, **CP6**, **60**, 66, **90**, **100**, 141, **147** |
| 21. 05/03 | §5.1-5.5 | Clausius & Kelvin-Planck statements of 2nd Law |
| 22. | §5.6-5.8 | Reversible/irreversible processes; the Carnot cycle |
| 23. | §5.6-5.8 | continued |
| 24. | §5.10 | Thermodynamic temperature scale |
| 25. 05/10 | Problems(5): | 5-**21**, 26E, 28,56, 57, **58E**, 63, 87, **97**, 103E, **130**, 131, **136** |
| 26. | §6.1-6.2 | Entropy defined; calculations |
| 27. | §6.3-6.5 | Increase of entropy principle; entropy generation |
| 28. | §6.6-6.9 | Diagrams; calculation of entropy change |
| 29. 05/17 | §6.10 | Entropy change, ideal gases |
| 30. | §6..11 | Reversible, steady-flow work |
| **31. 05/19 Wed** | | **2nd Mid-term exam: Chapts. 4,5 ** (6:30pm) **** |
| 32. | §6.12,13 | Adiabatic efficiencies; steady-flow devices |
| 33. 05/24 | §6.12,13 | continued, CyclePad demonstration |
| 34. | §6.14 | Entropy balance |
| 35. | Problems(6) | 6-**27**, **CP7**,35,42,**46**,56C,63,**79**,108,**133**,139 |
| 36. | Problems(6) | continued |
| *37. 05/31* | *Memorial Day* | |
| 38. | §7.1,2 | Exergy |
| 39. | §7.1,2 | CyclePad laboratory **CP8** |
| 40. | §7.3 | Second-law efficiency |

Curriculum: Creating CyclePad problems from textbook problems

The problems that we created for *Thermodynamics I* were based on problems from the students' textbook. We made that decision, in part, to keep the CyclePad curriculum tightly integrated with the standard course curriculum. To modify the book problems, we began by trying to solve the problems using CyclePad. This step often eliminated many problems because some problems were out of the scope of CyclePad or we encountered a bug in the software when we tried to solve them. When we did find a problem that was solvable, we could ask, "What's the point of this problem? What could the student learn from this?" As shown in Figure 18, the original problems often just asked the student to produce a numeric answer. We wanted students to go beyond that and to think about the implications of the result they generated and how those results related to the concepts that they were learning during the lectures.

For example, we would start by trying to solve a problem in CyclePad such as that given in Figure 10. Then we would discuss what principle or concept might be illustrated by the problem. In this case, Instructor O. explained to me that the problem could be used to illustrate the steam dome[35] since the substance is transformed from a saturated liquid through the vapor/liquid mixture phase to a saturated vapor. In the student version of the textbook the answer to the problem is given, thus it is only up to the student to figure out a path to the answer. Interestingly, the answer (-8°C) is the same as the original temperature stated in the problem description. The textbook, however, does not make mention of this or ask the student to comment or reflect upon this. This is where Instructor O. saw an opportunity to improve upon the learning experience of the student and use Cycle Pad's analysis tools to create a richer problem.

In the version of the problem that we developed for use with CyclePad, the student had to explain *why* the temperature is equal to the starting temperature (see modified problem in Figure 18). Instructor O. felt that it was

[35] The important learning point about the steam dome is that in the transition from a saturated liquid to a completely saturated vapor heat is required, however the temperature of the substance will remain the same.

important that students learn to evaluate answers and to think about how the theories link to specific problems and solutions. By making use of Cycle Pad's sensitivity tool, students were also asked to explore that relationship between the final temperature and volume. The sensitivity tool generates plots of the relationship of two variables. Thus students can choose a range of outlet volumes and see how the temperature varies. The focus of the modified problem was for students to think at a conceptual level rather than about number crunching.

Figure 18: Textbook problem with CyclePad modifications

| Problem 3-46 (Cengel, 1998; p. 172)<br>*Note:* Italics indicate modifications to original problem | Commentary |
|---|---|
| (original problem)<br>A piston-cylinder device with a set of stops contains 10 kg of refrigerant 134a. Initially, 8 kg of the refrigerant is in the liquid form, and the temperature is -8°C. Now heat is transferred slowly to the refrigerant until the piston hits the stops, at which point the volume is 400 L. | This problem does not ask the student to explain why there is no temperature change. |
| (modified version for CyclePad)<br>Determine the temperature when the piston first hits the stops.<br>*Hint: pick final phase saturated.*<br>*Explain the temperature difference between the start and stop.*<br>Determine the work done during this process.<br>Show the process on a P-v diagram<br>*Use sensitivity analysis to examine the relationship between the T at the inlet and the outlet volume.*<br>Answers: (a) –8°C, (b) 45.6 kJ | In our version, students must explain the concept behind the answer and explore it further by examining the relationship between temperature, pressure and volume. |

## Instructional Strategies: Representations of knowledge

Instructor O. used the seven lecture periods throughout the term to (a) show students how to use the software (b) demonstrate how to solve problems and (c) review homework problems. During Instructor O.'s CyclePad demonstrations, he showed students how CyclePad's representation of knowledge was, in fact, the same as the theories that they were learning in class. Instructor O. made explicit to students the link between the modeling choices they made in CyclePad and the thermodynamic concepts.

A vignette of Instructor O.'s typical instructional style is presented in Table 16. (Since he was teaching two sections of the same course, I was able look for themes both across lectures and across sections.) I have chosen this example because it illustrates how he used CyclePad as a platform for simultaneously explaining how to use the software from a functional perspective and how to think about CyclePad diagrams from a learning and conceptual perspective. In this example, he used a simple turbine system to illustrate how the state postulate, ideal gas law and property tables are used to solve for values in the system (as shown in Figure 19). Instructor O. demonstrates that if he changes the stuff[36] in the system the conditions under which to apply the ideal gas law.[37] In the transcript, I have underlined pertinent passages. In the second

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[36] "Stuff" is the term used by CyclePad to refer to the substance running through a system

[37] Professor L. had told us, after one of the students' exams, that several had made the mistake of applying the ideal gas law to water (which is not an ideal gas). One thing that Instructor

column, I provide commentary about how the passages relate to themes in Instructor O.'s teaching.

Figure 19 CyclePad turbine diagram used in teaching vignette

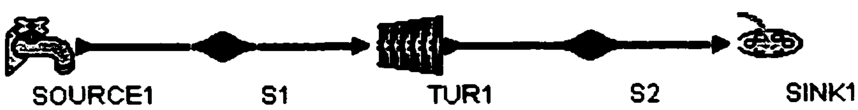



Table 16: Teaching vignette

| Narrative | Commentary |
|---|---|
| [Instructor O. is entering values into the meter window of the stuff[38] entering a turbine] [He first selects the temperature.] We'll assume 500 degrees C -- that shows up in green. And the two other parameters, which depend only on the temperature of the device, show up in blue because CyclePad knows those. We also want to assume pressure -- the two typical things we pick when we do these problems -- we say | Explains steps for using CyclePad to solve problem<br><br>Points out how CyclePad uses the state postulate[39] to |

O. and I felt was important was to illustrate points such as these which seem obvious to an expert in the field, but are subtler to some students.

[38] See 36.

[39] The state postulate is "the values of any two independent thermodynamic properties are sufficient to establish the stable thermodynamic state of a control mass composed of a pure simple compressible substance. [Howell, 1992 #285; p86]

| Narrative | Commentary |
|---|---|
| 10 atm. And CyclePad knows the rest of the intensive properties for this stuff. Because once you know two intensive properties for a stuff -- I think you guys have hit this -- ...you pretty much know everything about the fluid at that state. | solve for many values (this is why students need only enter temperature and pressure) |
| Not all of the numbers that show up in CyclePad inferred from assumptions we made are easy to track down. But since and since you're learning thermo you do want so see where those numbers came from. The way you do that is --we will use the volume as an example--you hold the mouse over it and click on it and ask why does the volume equal what it does.<br><br>[He then explains how to interpret the explanation window.] | Encourages students to develop an understanding through exploring the rationale behind CyclePad's calculated values |
| You can use this to hunt through any of the values that CyclePad comes up with... Let's say you want to know why little-v equals what it does. It says little-v equals what it does because it used the ideal gas law, that's that equation there. P=RT over little "v" and it knew these values for other things.<br>[He shows explanations for T and R too.] | Links the value CyclePad generated with the governing equations and explains how other values are calculated from the same formula. |
| ...Now lets say, for instance that we don't want this thing to be actually made of air. So we click on air, go to retract the choice air and it takes it away. Now it [the substance] is unknown. It still knows the temperature and pressure and | Shows how state postulate requires not only two independent states but also a specific substance to |

| Narrative | Commentary |
|---|---|
| mass because you put those in, but it doesn't know anything else because it needs to know what fluid you are working with. So if we go back to unknown and select the substances as being water. | calculate the other values. |
| You'll notice that the meter window changes a little bit. It still knows that the phase is gas and you could actually ask it why that is true. You'll notice its added these saturation properties, "v" sub "f", "v "sub "g" for water, since water can go through phase change because CyclePad uses tables. A minute ago we looked up v for air and we found out it used the ideal gas law. If we ask the same question for water, we find out that "v" equals what it does because CyclePad went in the tables and looked up the value for steam at that temperature and pressure. | Encourages inquiry into CyclePad assumptions<br>Demonstrates of application of laws depends on initial modeling assumptions<br>Shows students that CyclePad is not using the ideal gas law for water but using the property tables to calculate the volume. |
| (Instructor O. 4-2-99 Intervention Day #1, Section #1; Video 2 p. 3) | |

## CyclePad in *Thermodynamics II*

In fall quarter of 1996, before Instructor O. became the instructor for the CyclePad interventions, another members of our research (Student G.) team piloted several design problems (see problems in Appendix C) in Professor T.'s *Thermodynamics II* course. At that point, the software was not very stable—it crashed often and would run out of memory. This caused quite a bit of frustration for the students. By the following year, many of these technical difficulties had been fixed and we were eager to try again. In fall quarter of 1997, we implemented the same problem set with the same course and professor. In this section, I describe the evolution of the curriculum design and enactment in *Thermodynamics II* and how the context of the course (its students and regular Professor) was a major factor in shaping what ensued.

Professor T. was willing to let Instructor O. hold only one lecture during the term (as he had done with Student G.) While we requested more in-class time with the students, Professor T. felt that the students only needed the one demonstration of CyclePad. In Student G.'s demonstration, the students had been in a regular classroom and watched as he demonstrated CyclePad via a projection screen. The students were quiet throughout the class and never asked any questions. I was concerned that they would run into difficulties when they worked on the software on their own. For this reason, I suggested to Instructor O. that we hold the demonstration in the computer laboratory so that students could learn from a hands-on experience. Instructor O. created a written tutorial with screen images so that he could demonstrate some of the features of CyclePad to the students and then they could start the tutorial in class and then continue it on their own.

Students were also given the homework assignment to work on in their own time. Their only face-to-face contact with Instructor O. was in during the demonstration/tutorial. The students were able to contact Instructor O. and submit their homework answers through CyclePad's e-mail coach. When Instructor O. answered students' questions, he would send an e-mail to the whole class to inform them about a hint to solve a problem or a mistake in the wording of a question. By now the software was more stable, yet students still struggled to solve some of the problems Even with the hints they received, some students were unable to solve a few of the problems.

When we re-visited the curriculum for use in fall of 1998, we looked very closely at each problem to determine what students could learn. We found that some of the problems were too constrained and did not promote open-ended design work. Without this, problems became cookbook exercises. This realization led us to decide to drop two of the problems and create a new, open-ended design problem. As shown in Table 17, we eliminated two problems and added an open-ended design problem that was intended to encourage structural modification to a cycle to meet a minimum set of specifications. This problem was in the spirit of what CyclePad had been originally built for -- there was no unique right answer to this problem, students could create several topologies with different values for solutions.

Table 17. History of *Thermodynamics II* CyclePad assignments[40]

| Problem | Fall '96 | Fall '97 | Fall '98 | Comments |
|---|---|---|---|---|
| Turbojets for Cars<br>In this problem students analyze a car engine design. Students determine the optimum compression ratio, evaluate design tradeoffs and explain their results in words. | | | | Students were able to solve this problem and provide good rationales for their design decisions. They learned about design constraints and, specifically, tradeoffs between cycle efficiency, physical size and compression ratio. |
| Making Sure it's not the Heat, but the Humidity...<br>In this problem students set up a vapor cycle that uses a heat exchanger. The heat exchanger models a power plant that is using a river for cooling the substance. There are limitations on how much the temperature of the river can be raised without causing environmental problems. Students are to find out the highest plant efficiency given the constraints and comment on the relationship between turbine characteristics and heat discharged. | | | omitted | There was only one very specific design that satisfied the problem constraints. It required so many hints that little thought was left up to the students. Furthermore, the cycle had to be modeled in a specific way otherwise the students would encounter errors. Students would end up learning more about idiosyncrasies of CyclePad than about the problem itself. |
| Power from the Ocean<br>In this problem students create an ocean-thermal cycle that uses the difference in surface and ocean floor temperature to transfer heat between the seawater and cycle substance. The intent was for students to compare different substances in terms of performance, environmental impact and power plant design. | | | omitted | There was only one very specific design that satisfied the problem constraints. It required so many hints that little thought was left up to the students. Furthermore, the cycle had to be modeled in a specific way otherwise the students would encounter errors. Many students could only get the cycle to work for one |

[40] See Appendix F for complete text of problems.

| Problem | Fall '96 | Fall '97 | Fall '98 | Comments |
|---|---|---|---|---|
| | | | | substance. |
| <u>Putting the Ozone Back Where it Belongs</u><br>In this problem, students compare the design of a refrigeration system based on water instead of refrigerant-12. Students learn about how cycle properties (such as efficiency, size, mass and power requirements) differ depending on the substance used. | | | | Initially students had trouble building this cycle to meet the design constraints. They often could make it work for only one substance. We added several hints to the problem and changed some values so that they could more easily do the comparison. We kept this problem because Instructor O. felt that students should do one problem in which they compare substances since this is a unique feature of CyclePad and something they are not asked to do in typical book problems. |
| <u>Open-ended design problem</u><br>In this problem students are asked to design a power plant with a power output of 5.5 MW. They are instructed to start with a basic cycle and modify its topology to improve performance. | N/A | N/A | | Students had to work to create their own topology whereas the other problems specified a specific cycle design. Instructor O. felt that this problem would help students understand why certain design features (such as reheat or regeneration) improve cycle efficiency. |

We decided which problems to re-use and which to drop based on the feedback we got from students in the Fall '97 course. We decided that if the problem required too many hints from the instructor to complete, that it was not of value to the students. We also decided that problems should be illustrative of a general principle in thermodynamics or design, rather than focusing on minute details that were specific to certain topologies. For example, Instructor O. described the rationale behind eliminating the "Power from the Sea" problem:

> At least one of the problems we dropped because it seemed like we pretty much had to cookbook them through the entire process. ...we had to give specific clues like that this phase was saturated vapor and over here assume that this is 10 degrees colder than that water...so there wasn't much room for design alteration. Part of it was that the problem was meant to show that is a very limited system -- that [the] contraption isn't going to work very well— and part of it was that our [property] tables were narrow enough that you could easily find yourself out of bounds and that students just get stuck. (Instructor O. interview 7-28-99; tape1 p. 7-8)

Course Integration

Over the three years, we attempted to better integrate the CyclePad experience into the overall course. When G. first used CyclePad with the courses, he would do one demonstration of CyclePad using an overhead projector in the regular classroom to show students how to use the software. In '97 and '98, we had the class meet in a computer laboratory where we could demonstrate how to use the software and allow the students to try it for themselves. However, in both cases, we were limited to one lecture period. As Instructor O. had given up his office space in the engineering building several years ago, almost all further interactions with students took place through CyclePad's e-mail facility.

We were frustrated that Professor T. would not allow Instructor O. more class periods to interact with students. From our surveys of students, we had found that they did not perceive CyclePad to be well integrated into the course-- they described it as seeming "tacked" onto the class. Our concern was that we wanted to link what they learned from using CyclePad back into the class lectures. Without this, it would be hard for students to see the applicability of the CyclePad homework to the goals of the course. Thus, CyclePad was only a small slice of the overall course curriculum.

## Instructor O.'s Ideal of Teaching with CyclePad

Throughout the course, Instructor O. had struggled with when to use CyclePad to demonstrate concepts. Since he only had control of a handful of the lectures, it was particularly difficult to weave the content of his lectures with what students had learned from the regular course professor. By integrating CyclePad fully into the course, he could link explanations and demonstrations together. He explained the dilemma and his vision of a solution:

> We had this horse and cart issues... [if] you tried to introduce a function of the software-- without talking about it as a lecture topic-- it seems odd. Once [the students have] had it as a lecture topic, it seems trivial to do with the software. So if we were doing a course curriculum for a fully integrated course, we'd say, alright [laugh] now we're going to talk about this new property that you've seen just minutes before. Here's what it means and here's something you can do with it. (Instructor O. interview 7-28-99; tape1 p. 2)

Another issue that curtailed Instructor O.'s ability to create our "dream" curriculum was that several features in the software were not fully developed. This often forced us to abandon a problem. Instructor O. felt that because we knew the software had weaknesses, we limited how students interacted with it. Many of the hints that we added to the problems would not be required once improvements were made to the program's underlying thermodynamics knowledge base. Instructor O. explained that he was happy with the curriculum we had developed but that we could ask more of the students if we knew the software was more robust:

> I think the questions we would ask them wouldn't be very different except that we wouldn't have to edit the problems because of the software – but that is sort of a big deal, we can be a lot more aggressive about asking probing questions if we know that the software can hack it... (Instructor O. interview 7-28-99; tape1 p. 1)

Instructor O. also had ideas about how to reorganize the curriculum. As he explained it, engineering curricula start by teaching students the fundamentals of a domain and, in later courses, the application of those concepts to design problems or real-world systems. Recent reforms in engineering education are attempting to move away from this "capstone" approach and integrate design into all engineering courses. Instructor O. felt that this approach could be applied to thermodynamics courses. He hypothesized:

> You could invert a good part of how it's taught. You could start out by saying "here's a useful device that we use for getting power out of steam" so we have this source of heat and we want to get ... mechanical work out of it and turn it into electricity. How do we do that? Well, you know, here is how we'll do it. We'll put in some heat here and try to heat up a bunch of steam and add a lot of pressure to it and then we'll put it through a turbine and let the steam expand and spin the turbine around and that will be connected to a generator and that's how we'll get electricity. And we want to reuse the steam so we have to cool it down again and

> put it through a pump to get the pressure high again and start heating it to get it back to where we started.
>
> You can explain all those things without ever doing any numbers and not knowing anything more and go from there and say how does a heater work and now that we know the general idea of what we are trying to do and we have our motivation that we're trying to get power out of something, then how do you go back and analyze the heater. Well, this is what a heater is, you put a bunch of tubes that you put fire around and run your fluid through it and try and heat things up. How much heat do you add? How does it change and when you get to that level you can start explaining things like pressure and temperature. (Instructor O. interview 7-28-99; tape2 p. 9-10)

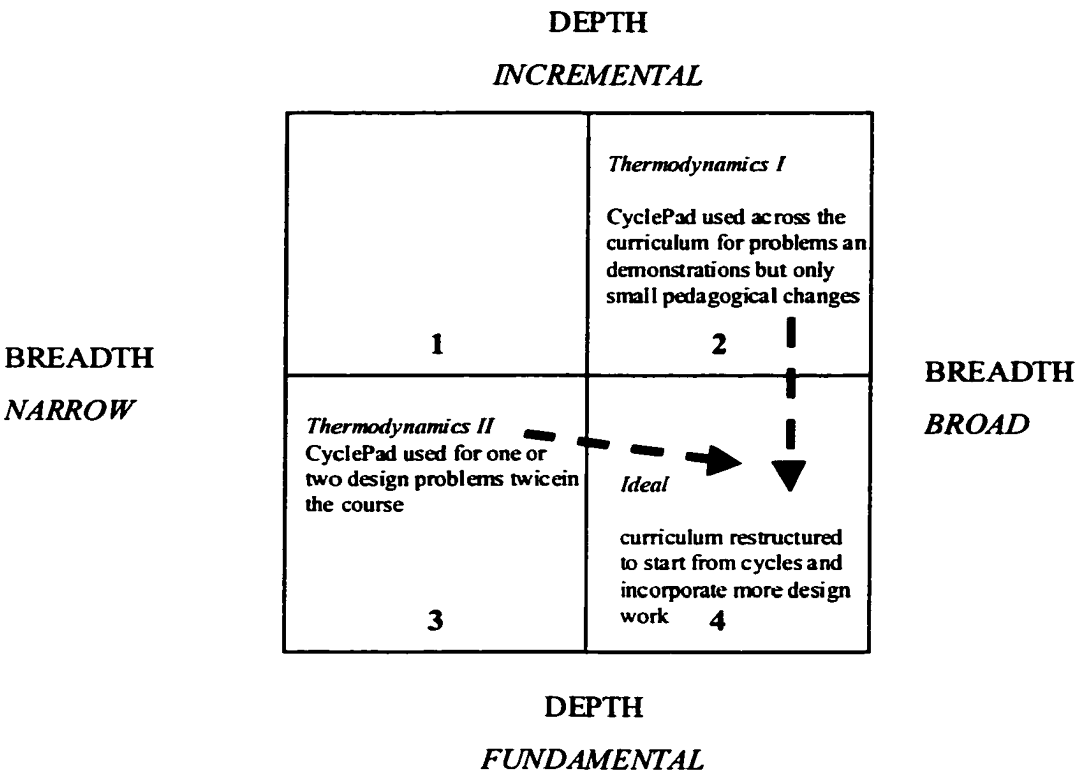
On several occasions throughout the CyclePad interventions, Instructor O. discussed his interest in developing a CyclePad textbook with our research group. We realized that by having control of both software development and curriculum design, we could ideally create a course that radically restructured how thermodynamics is taught. We had learned that professors would not necessarily be able or have the motivation to change how they taught thermodynamics without the support of curricular materials. We had hoped that professors could create some of these on their own, but, as we found at NWU, not all professors had the interest or motivation to do so.

### Summary

Instructor O.'s use of CyclePad in *Thermodynamics I* was broad in its coverage of curriculum, yet minimal in its impact on pedagogy. Students used CyclePad throughout the course, but mainly on textbook based problems (as shown in Figure 20, quadrant 2). Instruction consisted of lectures and demonstrations with few hands-on sessions. On the contrary, in *Thermodynamics II*, the CyclePad assignments were very different than traditional instruction. Students worked on building and analyzing cycle designs (see quadrant 3). However, there was minimal integration into the curriculum.

Instructor O. described the ideal teaching of thermodynamics as starting from cycles and working backwards to processes. He thought that the curriculum could be better integrated between the two courses so that students' CyclePad experience in *Thermodynamics I* would lead into more design work in *Thermodynamics II*. Quadrant 4 of Figure 20 shows Instructor O.'s ideal vision of teaching with CyclePad. The dashed arrows indicate the trajectory from the enacted course to the "ideal" course.

Figure 20. Instructor O.'s "enacted" v. "ideal" teaching




What would it take to transform each of the courses to the ideal? In terms of *Thermodynamics I*, the software is well integrated across the content of the curriculum, however from a pedagogical point of view, its usage was not novel. By restructuring the curriculum - moving away from the lock-step approach of the textbook to a more design-centric and problem based learning approach – CyclePad would be an even more effective instructional tool.

An important factor that would facilitate a move toward the ideal would be for Instructor O. to become a full time teacher for these courses and not just the CyclePad intervention instructor. This would give him more control of class time, curricular materials and student-instructor interactions. Instructor O.'s ability to innovate was bounded by Professor T. and L.'s willingness to collaborate and experiment in their classroom. For example, Professor L., who had been teaching thermodynamics for many years, was tied to current beliefs and practices in engineering instruction. After his experience watching Instructor O.'s CyclePad intervention, he wrote:

> Conclusion: CyclePad is well developed software that can be used to enhance a students ability to solve problems and stretch their understanding of thermodynamics by facilitating parametric studies of the influence of various parameters. However, it cannot

> replace traditional instruction in the basic ideas. (From e-mail to me 9/27/99)

In *Thermodynamics II* in addition to the limited access to students, another problem was that cycles are only one part of the content covered in the course. Fuller integration of CyclePad would require modifications to the software to better align with the remaining concepts. For example, the second half of the course covers topics such as chemical reactions and phase and chemical equilibrium. These topics are beyond the scope of CyclePad's knowledge base and would require significant development time to implement. In this case, the context of the tool itself and available curricular materials (i.e., the textbook) and the regular course professor were factors in shaping Instructor O.'s curriculum design and enactment.

# CHAPTER 7

# CONCLUSION

The goal of most progressive, constructivist reformers is to change current educational practices to be fundamentally different in instruction and broad in their curricular reach (i.e., a movement to the fourth quadrant of the model in Figure 21). As shown by these cases, often good intentions achieve only one of these aims. Thus, what might have been a radically different course becomes a traditionally taught course with a new software tool. Or a more engaging pedagogy is used with new materials but only for a brief moment. In order for technology to play a role in the re-designing of education, as many researchers have learned, it must be well integrated into everyday classroom and educational practices (Ehrmann, 1995; Hadley & Sheingold, 1993; Means, Blando, et. al., 1993). However, as these cases have shown, infusing technology into an existing course is not a simple process.[41]

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[41] The scope of the analyses in this dissertation is limited by the narrow focus on a particular software tool used for teaching in one domain of engineering. To further explore faculty's experiences with new technologies and how they negotiate their contexts, the usage of other software in different domains should be looked at. Also, one would also want to examine how the same professor would respond to different environments. It would be of benefit to study a population of professors who teach at several universities or those who make a career change from one school to another. In this way contextual differences could be compared within individuals but across institutions.

Figure 21: Examples of classroom change

DEPTH

*INCREMENTAL*

| BREADTH *NARROW* | | | BREADTH *BROAD* |
|---|---|---|---|
| | Example<br>new technology used in one unit or part of a course<br>1 | Example<br>new course curriculum using traditional pedagogy<br>2 | |
| | Example<br>radical change in instruction in one unit or topic<br>3 | Example<br>adoption of new pedagogy across entire course with re-structuring of curriculum<br>4 | |

DEPTH

*FUNDAMENTAL*

**Cross-case Comparison**

The cases presented in this dissertation represent several different perspectives on implementing technology in engineering classrooms. These studies show that professors take different approaches in their efforts to alter, the curriculum and pedagogical approach - the essence of their instructional practices. The three cases also illustrate how departments, supervising faculty and curricular standards play a role in shaping the outcome of proposed educational changes.

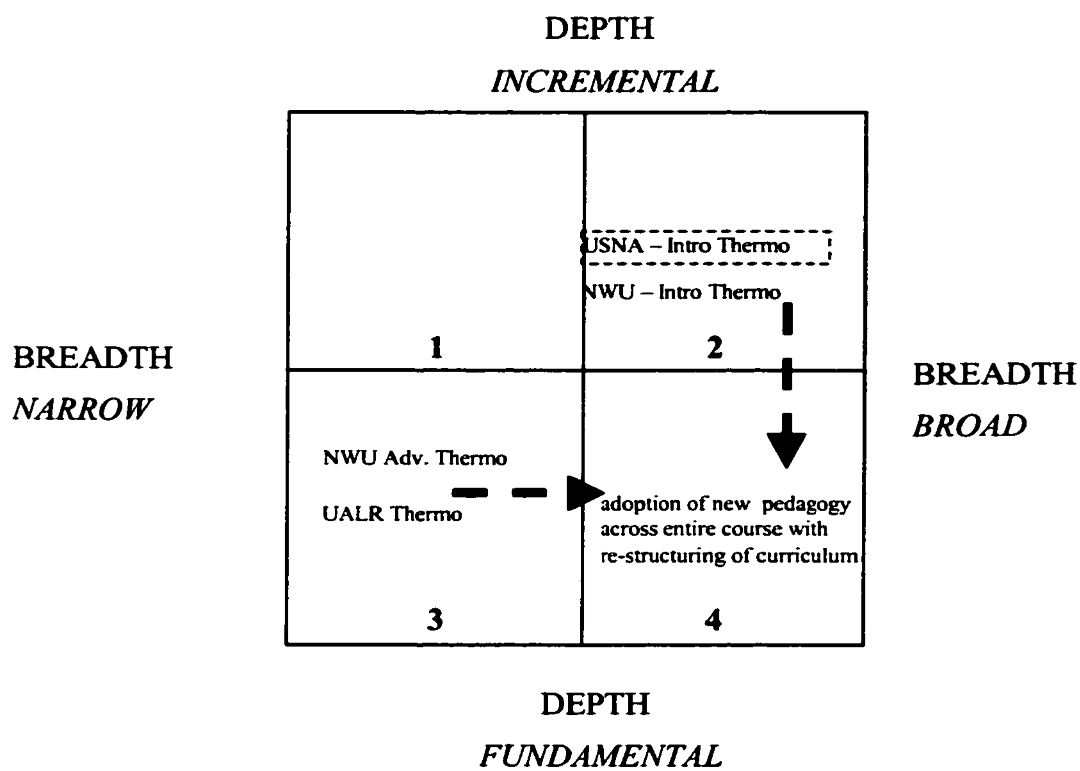
Professor P. at UALR had the most radical ideas about changing thermodynamics curriculum. Like Instructor O., he wanted to create a more design-based course that focused on linking the mathematics of the field with the native design intuitions of the students. Similarly to Professor R. at USNA, he wanted to use CyclePad throughout the course (not just for the sections on cycles). Professor P. was captivated by progressive pedagogical techniques that he read about in the educational literature. Of the three professors, he was the only one who was interested in improving students' communication skills and in promoting student-student interactions. In contrast, the courses at NWU and USNA remained focused on individual student performance and saw CyclePad more as a means for increasing instructional aid to students. In those classrooms, they promoted the features of CyclePad that would help explain concepts to students and thus supplement the activities of the instructor. Thus, while all three instructors were interested in reforming thermodynamics education, they focused on different instructional techniques.

Another distinguishing factor between the three cases was the level of authority the professors had in determining the curriculum for their courses. If placed along a continuum, Professor P. (UALR) acted with the most autonomy at the other end of the spectrum, Professor R. (USNA) encountered the greatest resistance and ultimately refusal to his proposed changes. Likewise, Instructor O. encountered resistance but, unlike Professor R. who was blocked at the departmental level, Instructor O. met resistance at the classroom level by the presiding faculty. As discussed at the end of this chapter, the context of the classroom – the university, it's goals and mission, the role of the department – was an important factor in how the professors developed and negotiated changes to their courses.

The three professors share a similar problem in developing new curricula for a subject area that is usually taught from a single textbook. In particular, the structure how knowledge is presented – the organization of the concepts, the building of individual units of knowledge upon one another – leaves little room for innovation. As the professors worked to create curricular elements that employed CyclePad, they found it difficult to link these activities with the content of the students' textbook. When they created problems that were based on those in the books, the problems lacked the open-ended and exploratory nature of engineering design problems. While the professors could create parts of the curriculum that used CyclePad, they lacked the time and resources to develop a fully integrated CyclePad course.

In terms of the trajectory of change (see cross-case comparison Figure 22) the introductory courses at NWU and USNA increased the usage of CyclePad throughout the courses, but with little innovation in pedagogy. In contrast, the advanced course at NWU and Professor P.'s one-term thermodynamics course at UALR introduced new pedagogical approaches to the domain (design-based learning) yet in only modest amounts. This is discussed in greater detail below.

Figure 22: Cross Case Comparison



Breadth of Change

The degree to which technology becomes a part of curriculum depends on several factors such as the effort needed to create new curriculum and the degree of support for innovation in the classroom. During the time span of this dissertation, the features of CyclePad were augmented to allow for greater integration into introductory thermodynamic courses. While the program had been originally created for open-ended design work, through our collaboration with professors we learned that it also needed to support students in learning the basic of thermodynamics through simple systems. By adding several new features professors were able to use the software in other parts of the curriculum.

The curriculum that professors developed for CyclePad arose from their pedagogical content knowledge -- knowledge of the subject area, knowledge of curricular and instructional practices and an understanding of their students. Drawing on this, professors created problems and activities that were tailored to the specific needs of their classrooms. In these cases, the instructors were instrumental in the curriculum development rather than instruments of the work of others (Paris, 1993). This required more input on the part of the professors than, for example, when they teach straight from a textbook in an introductory course. The professors had to make time to create and test CyclePad assignments. As found in the surveys in Chapter 2, schools and departments are more likely to encourage the use of technology than to offer release time from teaching to develop new curriculum. While it is beneficial for professors to create their own curriculum that is tailored to their students, the constant updating and revising of curriculum can become a burden (especially for those with a high teaching load).

Professor R. could dream up a brand new curriculum while under the impression that he would be granted an experimental section. When that did not happen, he curtailed his plans. Similarly, Instructor O. knew that CyclePad could be used in more innovative ways, but was limited by the course professors in the amount of class time and amount of homework problems that could be spent on CyclePad. At UALR, Professor P. is the only teacher for *Applied Thermal Sciences* and there were no departmental standards, so he had more freedom to change the course content and materials. Similarly, in Professor R.'s advanced course he developed a curriculum that used journal articles for reading materials along side CyclePad and other software tools. In contrast, Instructor O. at NWU was beholden to the regular course professors who had ownership of the overall curriculum and determined the extent to which Instructor O. could participate in curriculum design and delivery. A factor that is key to change, is the degree of autonomy that professor's perceive they have and how they act.

Departments perceive a need for standardizing curricula in multiple-section courses. By standardizing what is taught, professors who are down stream in the engineering curriculum can ensure that all of their students have learned the same things in the pre-requisite courses. Standardization in thermodynamics is expressed through uniformity of textbooks across sections. The case of USNA is one of extreme uniformity across sections where not only are texts shared but exams as well and the department has veto power over pedagogical experimentation. These practices, which occur in sciences and engineering at most universities, preserve the status quo and raise the locus of curricular change from the individual classroom level to the departmental level (as the case of Professor R. illustrated). Furthermore, as seen at USNA, departments have concerns about student performance on professional exams, which may also shape their views on how engineering courses should be taught. Thus, one must look beyond the individual professor to understand and identify the larger context in which he or she operates to understand the external boundaries professors perceive they are operating within.

## Depth of Change

In the two courses that closely followed a textbook, there was little depth of pedagogical change. For example, when Professor R. used CyclePad in *Engineering Thermodynamics* for solving textbook problems, he employed a traditional pedagogical approach. Likewise, Instructor O. made some changes in pedagogy in *Thermodynamics I* by modifying the textbook problems but he was still limited by the structure of the overall curriculum. It was difficult to construct design problems that fit with a bottom-up rather than top-down approach. Changing pedagogy often requires changing epistemological beliefs. To support a new epistemological stance for teaching has implications for professors' choice of supporting materials (e.g., textbooks and software). Embodied within a textbook or piece of educational software is a belief about what knowledge is valid and important and how students display their understanding of a domain. This often carries with it an expectation for certain pedagogical approaches to teaching the subject matter. For example, most thermodynamics textbooks expect a linear, step-by-step, lecture-based pedagogy. By believing that students demonstrate knowledge through solving numeric problems by hand, these materials do not demand students to exhibit deeper conceptual understanding or to link between pieces of knowledge. This approach perpetuates the problem of students creating knowledge that is inert (Whitehead, 1916; Perkins, 1985). In contrast, CyclePad was developed with a top-down view of thermodynamics in which students start by creating cycles and then analyze the parts to learn the underlying concepts.

Through creating new curricular ideas and materials -- such as the design problems Instructor O. used in *Thermodynamics II*, Professor P.'s *Applied Thermal Sciences* laboratory exercises or Professor R.'s *Energy Conversion* term projects – newer, more progressive pedagogies (e.g., problem-based learning, design-based problems and group work) can be woven into the classroom. While both Instructor O. and P. achieved this in isolated instances during their courses, it would take more effort and curriculum development to span the whole course. Only Professor R. was able to achieve this level of implementation. This was due to the fact that he had both the authority to teach the course as he wished and time to develop curriculum. Instructor O. lacked the former while Professor P. struggled with the latter – he had many good ideas but ran out of time to implement them. With time it would be possible for Professor P. to migrate his course towards his ideal whereas Instructor O., without control of the course, would have an uphill battle.

Again, as with the breadth of change, crucial factors were the time and effort required to make significant pedagogical improvement and the degree to which the other community members, whether at the professor or departmental level, supported radical curriculum and pedagogical reform.

## Context and Change: Implications for Theory

The focus of this dissertation was on teaching practice at the classroom level. However, in analyzing these cases, it is apparent that professors are negotiating contexts beyond their classrooms - levels from the school/university to the department to the classroom. For example, at the school level, Professor P. was concerned that the addition of a new school within the university (for telecommunications and technology sponsored by local employers) would lead to a change in the department with which he was affiliated. This, in turn, might change his teaching assignment and possible alter his tenure clock. In regards to the CyclePad curriculum, he was unsure as to whether he'd even be teaching *Applied Thermal Sciences* if he became part of a new department. At the departmental level, in the case of USNA, Professor R. was pressured by his department to teach *Engineering Thermodynamics* with minimal usage of CyclePad. The department was responding to Professor R. based on its perception of the importance of preparing students for the Professional Engineer exam on which students would not be able to use software aids to solve problems. In this example, it is both a national standard and local department actions that shape the context of Professor W's classroom. These examples illustrate "multiple embedded" contexts of engineering instruction: subject, students, colleges, university, employers, professional contexts, and institutional environment (as illustrated in Chapter 1, Figure 4). These nested environments are the spaces which professors negotiate in defining classroom practices.

In examining instructors' teaching practices, it seems that the role of context has been under-emphasized in models of pedagogical content knowledge. The instructors' knowledge of students was entirely context-specific. For those who take a constructivist view on learning, what professors know about their students' prior knowledge is central to how they would structure teaching. For example, Professor P. knew that many of his students were interested in cars and auto racing. He could use this information to both motivate and anchor thermodynamic instruction by starting with the related cycles (e.g., Otto and Diesel cycles) and building students' knowledge from there. The rationale for his curriculum design was based on knowledge specific to those students he taught at UALR. In particular, their limited background in mathematics which Professor P. found to be endemic to the engineering technology program at UALR but not an issue for the students whom he taught at Yale's engineering science program. Likewise, Professor R.'s concern about his students' heavy academic and extra-curricular load, again, was specific to the culture of the Naval Academy and not an issue for the students he taught at Johns Hopkins. Based on this understanding of the students at their universities, these professors created curriculum to suit their particular needs. While it is expected that students vary across institutions and that professors tailor their teaching to the audience, this understanding is not prevalent in the literature on higher education.

In Shulman's model of pedagogical reasoning (Shulman, 1987) he posits that teachers translate their "knowledge of students" from a generic form to one that is specific to the students in their classroom. While teachers in K-12 may have studied common misconceptions of students in a certain domain or characteristics of particular age groups, faculty in higher education receive no general training. For the majority, their knowledge of students is specific to the institutions where they were trained as graduate students and their experiences in at the institutions that hire them. Thus, the knowledge of students that they develop, I would argue, is almost entirely based on their personal experiences and thus highly context specific. In turn, the teaching strategies they use and curriculum they develop contain elements that are specific to their students and their university context. This viewpoint echoes Shulman's critique of his own work (as described in Chapter 1) in which he claims that the purely psychological approach to studying teacher cognition needs to take into the account research on school context (especially Talbert and McLaughlin's). Furthermore, research on school context needs to be expanded beyond K-12 to understand higher education in and of itself. The model presented in Chapter 1 for the context of engineering education is only a beginning point in identifying the groups and organizations that professors negotiate in their teaching practices.

## Implications for Technology Design and Development

This research indicates that there are several ways in which technology usage can be improved in universities. First, by promoting research on teaching as a valuable pursuit, universities can support professors in increasing our knowledge about domain-specific teaching practices while at the same time increasing our understanding of the usage educational technologies.[42] This is especially important if we are to increase our understanding of education in the professions and technical fields where there are few educational researchers working. As found in the survey in Chapter 2, the engineering technology programs were staffed by professors with a greater interest in teaching and supported by department that emphasized improving teaching practices. Furthermore, these schools had fewer resources for scientific research in terms of funding and equipment (National Science Board, 1998). For professors with limited research infrastructure or funding and heavy teaching loads (such as Professors P. and R.), research on teaching serves double-duty. Time spent teaching also becomes time spent researching.

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[42] As mentioned in Chapter 1, Lee Shulman, in his work with the Carnegie Commission Shulman, is leading an effort at the Carnegie Foundation for the Advancement of Teaching, to help develop discipline-specific understandings of university teaching practices. In many of his recent writings, he has been trying to increase the prestige of scholarship on teaching (CITE).

These schools should become centers for excellence in teaching research and curriculum development.

Second, funding needs to be made available for professors and educational researchers to develop new curriculum that supports novel technologies. Curriculum design and technology-development are labor-intensive and costly activities. In the cases presented here, both Instructor O. and Professor R. used outside funds to support their time spent on curriculum development. Professor P., who had many good ideas, simply ran out of time to fully develop them. While it is laudable for individual professors to develop their own curriculum around specific technologies, this structure is not scalable to hundreds of classrooms or universities. One possible solution is for universities, funding agencies and curriculum designers (such as textbook publishers) to engage in partnerships in the initial development of both the technologies and curriculum. Professors could customize a curriculum to their classroom more easily than creating one from scratch.

Third, professors want technologies that can expand the viewpoints and experiences presented to their students. As found in the survey in Chapter 2, professors of thermodynamics want new tools that can help them bring real-world engineering systems into the classroom. They want technology to provide them with resources that are currently unavailable and prohibitively difficult to use in classroom learning. They do not ask for systems that would replace the professor (such as tutoring systems) but they want systems that expand students' horizons and offer new ways of presenting material in the classroom.

In certain domains of engineering, and thermodynamics in particular, little pedagogical change has taken place for decades. When a new tool, such as CyclePad, attempts to approach the domain from a different perspective, there is a large gap between the technology and the existing textbooks. The textbooks, whose fundamental pedagogical approach was developed before the invention of the computer, need to be updated to reflect recent advances in both educational technology and engineering education. This is no small task. Many efforts at technology development that stem from university research are limited in their scope and unable to become viable commercial projects. Textbook companies do not have expertise in new technology development or specific content areas and thus tend to limit their efforts to creating on-line versions of their existing materials. By leveraging the expertise of different organizations, from the curriculum designer to the software researcher/developer and educational evaluator, new technologies can be developed with associated curriculum that have a greater potential for widespread adoption and implementation. These types of partnerships are increasing, as universities want to expand into the distance-education marketplace but lack the infrastructure to launch such an endeavor (in terms of technology development and deployment) that for-profit companies can provide.

Through a combination of increased scholarship on university teaching and new curriculum and technology resources that meet professors' pedagogical goals, higher education can begin to reinvent itself.

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# APPENDIX A

## INTERVIEW PROTOCOL

The content for these interviews was based on several sources. Interviews #1-5 were adapted from protocols used by Grossman (1990). Other sources for interview content were: Ruscio (1987) on role as an academic, Boyer (1990) on context factors such as departmental pressures, and Bourne, et. al. (1995) on engineering.

### Interview #1: Knowledge/Conceptions of Thermodynamics and Teaching Thermodynamics

**A. Educational Background in Thermodynamics**

- Can you tell me about your background in Thermodynamics?
- Courses you took - undergraduate/graduate, favorite/least favorite
- What areas did you concentrate on? Specialization?
- What do you feel are your strengths in thermodynamics?
- What area, if any, do you feel that you are weak in?
- What areas are easy for you? Are any difficult?
- Tell me about any significant work you did in the field of thermodynamics as an undergraduate or graduate student.

- Tell me about any significant work you did in the field of thermodynamics as an undergraduate or graduate student.
- Tell me about any work you did in thermodynamics in a non-academic environment.

**B. Knowing Thermodynamics**

- What do you think it means for someone to know thermodynamics? If someone is an "expert" in thermodynamics, what would you expect them to know?

**C. What is Thermodynamics?**

- Could you tell me about the sciences that make up Thermodynamics? Tell me how the areas are related to each other. (Could you draw a map of the different areas and their relationships?)

**D. Teaching Thermodynamics**

- What made you decide to become a thermodynamics/mechanical engineering professor? Why did you decide to teach this particular topic?
- Tell me about what you see as the reasons for studying thermodynamics as part of several engineering disciplines (mechanical, civil, etc...). What are your goals for your students? What areas do you think are important to cover in class.
- What should students be able to do? How would you know they can do it?

- What do you think makes thermodynamics difficult for students? What areas do you think they have problems with? How do you know? What is easy for them? What could make the study of thermodynamics easier for students [probe for both use of tools and aids as well as different teaching styles]
- Tell me about the classes that you are teaching this semester. How are the classes organized? Why? What textbook are you using? What units will you cover? Have you taught with this text before?
- Tell me about the students in your class.
- Tell me about any other experiences that influence how you teach thermodynamics.
- Tell me about the best and worst teacher you ever had (in engineering and in general). What made this teacher the best/worst? How has she/he influenced the way you teach?

**Interview #2**

- (Choose a concept to focus the interview around)
- Tell me about this concept. How might you explain it to a colleague?
- Could you talk about some of the things you would think about if you had to teach this concept? What are some of your first thoughts about teaching this concept?
- What would be your goals for teaching this concept? What would you want students to walk away with?

- How might you teach this concept in a course? What units might you use it in?
- Can you tell me about some activities you might do around this concept? What kind of assignments might you use?
- Tell me about the difficulties that you might expect students to have with this concept. How might you help them overcome these problems?
- Let's say a student had the following questions. How might you respond to them. [role-play situation]
- How would you formally evaluate students' understanding of this concept? How might you find out informally whether they understood it or not? How might you have them demonstrate their understanding?

**Interview #3: Views and Personal History**

**A. Teaching**

- Why are you teaching? If you could do it all over again, what would you do (would you still be a professor?)?
- What does it mean to you to be an academic? Describe a model of an outstanding academic.
- What do you see as your primary responsibility within this institution? How do you divide your time in a typical week between teaching, research, advising and other responsibilities?

- How do you feel that teaching in a teaching college is different than in your undergraduate and/or graduate institution? Do you think that you teach differently than the teaching you observed in your own schooling?
- Have you taught elsewhere? What have you taught? Are your teaching practices significantly different here? How? Why?
- What types of technology do you use in teaching? What types of laboratory equipment? Why?

**B. Department/School/University**

- How important do you think teaching is in tenure decisions? How important are student evaluations?
- How important is publishing in tenure decisions?
- Do you feel pressure from other faculty to teach in a certain way? (If you raise the teaching expectations of students is that seen as a problem?)

**C. Students**

- How do you feel about your students in general?
- Do you think students have changed since you were a student? If so, how?
- How prepared do you feel students are by lower schooling or previous course work? Are there any gaps that you feel you need to make up for?
- How do you feel about your students work ethic? What do you think their goals are post-graduation?

- What do you see as your role in educating students for the workforce? Do you expect any of your students to end up in research environments (either corporate or academic)? Do you expect any students to pursue education beyond a B.A. or B.S.?

**D. Advising**

- What does your department require you to do in terms of advising students? Are you assigned/selected to be the advisor for specific students?
- How do you view your role as an advisor? What do you feel you can offer students?

**E. Engineering**

- In general, what do you think good engineers need to know?
- In terms of teaching, how important do you think hands-on experiences are? Design work? Theoretical work? Problem solving? What do these terms mean to you?
- How do you feel about the laboratory opportunities for students? What's missing? Are they linked to course work? Is the equipment current or out-of-date? Why?
- In your opinion, what are the most important curriculum-related issues facing engineering education?

- **Do you think there is any need for change in engineering education? If so, what types of change?**
- **Do you find ABET to be a catalyst or barrier to innovation?**
- **Do you worry about the accreditation of your schools' engineering programs?**
- **Do you belong to any engineering professional societies? Which ones?**
- **What do you think are the primary forces for change in engineering schools? [probe for within school and external factors]**

**<u>F. Personal History</u>**

**Get copy of C.V.**

**Interview #4: Planning for the fall CyclePad course**

- **Tell me about the design for your course this fall.**
- **Do you have any concerns about the course?**
- **What are your goals for the students?**
- **Did planning for this course differ from other courses you have planned for? How so?**
- **What materials do you plan to use?**
- **Did the department require the text or did you choose it?**

**Interview #5: Retrospective interview on the teaching of a particular unit**

- Tell me about this unit on ________. (pick same topic for each interviewee)
- How did you introduce it?
- What were your goals for the unit?
- What kind of things did you take into consideration in planning the unit?
- Can you tell me about some of the class periods?
- How long did the unit take?
- Tell me about the students in the class.
- Tell me about the assignments that you used in the unit. [Get copies]
- Was there any test associated with the unit? [Get copies]
- What are you teaching regarding problem solving?
- Tell me what you thought the students got out of the unit.
- Tell me how you thought the unit went. How would you change it if you taught it again?
- How might you change it if you were teaching a stronger group of students? a weaker (or younger) group?
- Where did you grow up?
- What schools did you attend?
- How early did you decide that you would become an engineer and/or professor?
- Was your family important in your decision to become a professor?

APPENDIX B

## I. Faculty Survey

This survey is part of a research project on thermodynamics education being conducted at Northwestern University. It is for educational research purposes only, and the results will be kept anonymous.

For tracking purposes, please enter the following:

Name: ___________________________________

Your E-mail: ______________________________

University: _______________________________

Department: ______________________________

***************************************************************************************

There are 22 questions below some multiple choice, some short answer.

Please answer the questions to the best of your ability.

1. How many years have you been teaching?

2. How long have you been teaching thermodynamics?

3. What thermodynamics courses have you taught? List course titles here:

4. What do you want students to learn in your courses?

**4. What do you want students to learn in your courses?**

**5. What are the challenges you find in teaching thermodynamics?**

**6. What teaching styles do you use in class (lecture, group work, collaborative learning, etc)?**

**7. Rate how easy it for students to understand:**

**Choose N/A if the concept is not covered in your course**

| | Very Hard | Somewhat Hard | Neither easy or hard | Easy | Very Easy | N/A |
|---|---|---|---|---|---|---|
| 1st law of Thermodynamics | o | o | o | o | o | o |
| 2nd law of Thermodynamics | o | o | o | o | o | o |
| entropy | o | o | o | o | o | o |
| internal energy | o | o | o | o | o | o |
| enthalpy | o | o | o | o | o | o |
| reversibility | o | o | o | o | o | o |
| efficiency | o | o | o | o | o | o |
| T-s diagrams | o | o | o | o | o | o |
| P-v diagrams | o | o | o | o | o | o |
| Work transfer | o | o | o | o | o | o |
| Heat transfer | o | o | o | o | o | o |
| Closed v. open systems | o | o | o | o | o | o |

8. Rate your students' ability to do the following:

Choose N/A if the concept is not covered in your course

| | Very low | low | Average | High | Very high | N /A |
|---|---|---|---|---|---|---|
| Given 2 properties (e.g, T, P) determine the state | o | o | o | o | o | o |
| Given 2 properties (e.g, T, P) interpolate other properties (e.g, u, h, v) | o | o | o | o | o | o |
| Make simplifying modeling assumptions | o | o | o | o | o | o |
| Select appropriate formulas | o | o | o | o | o | o |
| Apply formulas and equations | o | o | o | o | o | o |
| Know where or how to begin solving a problem | o | o | o | o | o | o |
| Work through a problem to correct final solution | o | o | o | o | o | o |
| Turn word problem statements into diagrams or pictograms | o | o | o | o | o | o |
| Solve open-ended problems (where there are no pre-defined answers) | o | o | o | o | o | o |
| Perform routine calculations | o | o | o | o | o | o |
| Use modeling assumptions to reduce 1st and 2nd law formulas | o | o | o | o | o | o |
| Convert units | o | o | o | o | o | o |
| Link problems to real-world applications | o | o | o | o | o | o |
| Explain thermodynamics concepts | o | o | o | o | o | o |
| Distinguish heat from temperature | o | o | o | o | o | o |
| Use a logical problem solving methodology | o | o | o | o | o | o |

9. In working through textbook problems what do you think students learn?

10. What difficulties, if any, do students experience solving textbook problems by hand?

11. What do you think is the benefit of solving problems by hand?

12. What do you think are the drawbacks of solving problems by hand?

13. What laboratory resources do you have available for teaching thermodynamics? Check all that apply:

- ❑ power plant
- ❑ Rigid (closed) tank laboratory equipment
- ❑ engines & motors
- ❑ Heat Exchanger
- ❑ refrigeration systems
- ❑ Heat Pumps
- ❑ HVAC
- ❑ Other:
- ❑ Piston apparatus laboratory equipment

14. Rate the extent to which you agree or disagree with the following statements:

(1=disagree, 2=disagree with reservations, 3=neutral, 4=agree with reservations, 5=agree)

— Students are motivated to learn thermodynamics

— Students have a positive attitude towards learning thermodynamics

— Students are apprehensive about learning thermodynamics

15. How would you change the way you teach Thermodynamics if you had unlimited time and resources?

16. What type of school do you teach at?

- Private Research University
- Public (State/Government) University
- Community College
- Military
- Liberal arts
- Technical College
- Other

17. Is your department in Engineering Technology or Engineering?

- Engineering
- Engineering technology

18. Do your interests lie primarily in research or in teaching?

- Research
- Leaning to research
- Equally research and teaching
- Leaning to teaching
- Teaching

19. Is your teaching influenced by any particular educational theories or research? Which ones? Where did you learn about them?

20. Rate the extent to which you agree or disagree with the following statements:

(1=disagree, 2=disagree with reservations, 3=neutral, 4=agree with reservations, 5=agree)

- My school/department encourages me to try out new computer technologies for teaching
- My school/department offers incentives to use technology in teaching (such as extra funding, course or software development time, etc.)
- My school/department expects me to use specific technologies in the classroom
- My school/department offers summer funding to work on curriculum development
- My school/department offers technical assistance for using technology in the classroom (such as technical expertise or training)
- My school/department offers release time from teaching for curriculum development
- Course evaluations influence my decisions to change how I teach
- My school/department discusses my course evaluations with me
- My school/department offers constructive feedback to help improve my teaching
- Teaching is important in tenure decisions
- Good teaching is rewarded by my department

21. Do you have tenure?

- yes
- no
- N/A (not applicable)

22. Do you have experience working as an engineer in industry?

- yes, number of years:
- no

Thank you for your input. If you have any comments about this survey please enter them below:

## II. List of Schools

Alabama A&M
Alfred University
Arizona State University
Auburn University
Binghamton University
Bluefield
Boston University
Bradley University
Brigham Young
Brown
Bucknell
Cal State Los Angelos
Cal State University: Chico
Cal State University: Fresno
Cal State University: Long Beach
Cal State University: Pomona
Cal State: Northridge
Cal State: Sacramento
California Inst. of Technology
CalPoly
Carnegie Mellon
Case Western
Catholic University
Cedarville
Central Connecticut University
Central Washington University
Christian Brothers
City University of NY
Clarkson
Clemson
Cleveland State University
Colorado State University
Columbia
Cooper Union
Delta College
Drexel
Duke
Eastern Washington
Erie Community College
Farleigh
Florida Atlantic U
Florida Institute of Technology
Florida International University
Florida State
Gannon
George Washington University
Georgia Tech
Harvey Mudd
Hofstra
Howard
Illinois Inst. of Tech
Indiana Institute of Technology
Indiana University - Purdue School of Engineering & Technology
Iowa State
Johns Hopkins
Kansas
Kansas State
Lakeland community College
Lamar
Layfayette
Lehigh
Louisianna State
Louisianna Tech
Loyolla Marymount
Manhattan College
Mankato State, Minnesota
Marquette University

Metropolitain State College of Denver
Michigan State
Michigan Technological Institute
Milwaukee School of Engineering
Mississippi State University
MIT
Montana State
Montana State Bozeman
Naval Postgraduate School
NC State
New Jersey Institute of Technology
New Mexico State
New Mexico Tech
North Carolina State
Northeastern
Northern Arizona University
Northern Illinois
Norwich University
Oakland University
Ohio Northern University
Ohio State
Ohio University
Oklahoma State
Old Dominion University
Oregon State
Penn State
Penn State - Behrend
Polytechnic University
Portland State University
Prairie View A&M University
Princeton
Purdue
Purdue Calumet
Purdue Tech
Purdue University North Central
Rensallier
Rice
Rocherster Institute of Technology
Rose-Hulman
Rowan University
Rutgers
Saginaw Valley State
San Diego State
San Francisco State
San Jose State
Santa Clara University
Seattle University
South Dakota School of Mines and Technology
Southern Illinois Carbondale
Southern Illinois Edwardsville
Southern Illinois-Carbondale
Southern Methodist
Southern Polytech
Southern University and A & M
St. Louis University
Stanford
State Technical Institute at Memphis
SUNY Buffalo
SUNY Farmingdale
SUNY Morrisville
SUNY stoneybrook
Syracuse
Temple
Tennessee State Nashville
Tennessee Technological Institute
Texas A&M
Texas Tech
Tufts
Tulane
Tuskeegee
Union

University of Akron
University of Alabama
University of Alabama Birmingham
University of Alabama Huntsville
University of Alaska Fairbanks
University of arizona
University of arkansas
University of California, Berkeley
University of California, Davis
University of California, irvine
University of California, los angeles
University of California, san diego
University of California, santa barbara
University of Central Florida
University of Cincinnati
University of Colorado, Bolder
University of Colorado, Denver
University of Connecticut
University of Dayton
University of Dayton
University of Denver
University of Evansville
University of Florida
University of Hartford
University of Hawaii, Manoa
University of HoUniversityston
University of houston
University of Idaho
University of Illinois- Chicago
University of Illinois- Urbana
University of Iowa
University of Kansas
University of Kentucky
University of Louiville
University of Maine
University of Maine
University of Maryland Baltimore County
University of Maryland, College Park
University of Massachusetts Amherst
University of Massachusetts Dartmouth
University of Massachusetts Lowell
University of Memphis
University of Miami
University of Michigan
University of Michigan Dearborn
University of Minnesota
University of Mississippi
University of Missouri - Columbia
University of Missouri - Rolla
University of Nebraska - Lincoln
University of Nevada - Las Vegas
University of Nevada - Reno
University of New Hampshire
University of New Haven
University of New Mexico
University of New Orleans
University of North Dakota
University of Notre Dame
University of Oaklahoma
University of Pennsylvania
University of Pittsburgh
University of Rhode Island
University of Rochester
University of South Carolina
University of South Florida
University of Southern Alabama
University of Southern California
University of Southern Colorado
University of Southern Mississippi

University of Southwestern Louisianna
University of Tennessee - Knoxville
University of Texas - Arlington
University of Texas - Austin
University of Texas - El Paso
University of Texas - San Antonio
University of Texas Pan American
University of the Pacific
University of Toledo
University of Tulsa
University of Utah
University of Vermont
University of Virginia
University of Washington
University of Wisconsin - Madison
University of Wisconsin - Milwaukee
University of Wisconsin - Platteville
University of Wyoming
US Airforce Academy
US Coast Guard
US Military Academy at West Point
Utah State University
Valparasio
Vanderbilt
Villanova
Virginia Military Institute
Virginia State University
Virginia Tech
Washington State
Washington University
Wayne State
Weber
Wentworth Institute of Technology
West Virginia University
Western Kentucky University
Western Michigan
Wilkes
Witchita State
Worcester Polytech
Wright State
Yale
Youngstown

APPENDIX C

# NU CYCLEPAD HOMEWORK PROBLEMS:

# THERMODYNAMICS II 1998

## Instructions to Students

### Submitting Homework

Homework can only be submitted via e-mail (no printouts, no diskettes). CyclePad has a built in e-mail facility as described below. This is very easy to use, the only thing to remember is to use the **Design Notes** under the **Edit** menu to answer text-based questions.

CyclePad problems can be submitted electronically directly through the program. Once you have completed a design choose **E-mail Coach** from the **Help** menu. Enter your return e-mail address and an appropriate subject line ("problem 1"). All design notes will be automatically included in the e-mail. The "to" field should read **robota@cs.nwu.edu.**

The first homework is due by October 28th. You can submit individual problems as you finish them.

The second homework is due Nov 13th.

### Getting Help

The TA for CyclePad problems is Mike Brokowski. You can reach him via e-mail at **robota@cs.nwu.edu.** You may want to e-mail the design you are having problems with. To do this choose **E-mail Coach** from the **Help** menu. You can type your question in the comment window of the e-mail dialog. Click the radio button for "I need help finishing this analysis" or "I need help with this contradiction."

Click the radio button for "I need help finishing this analysis" or "I need help with this contradiction."

You can also try our automated design coach by e-mailing designs and selecting "How do I <increase> the Cycle <Parameter>"

### Software

CyclePad is available in the lab at MG45. You can also download your own copy at:

http://www.qrg.ils.nwu.edu/software/software.htm

This software runs best under Windows 95 or Windows NT. It will also operate under Windows 3.1 or Windows for Workgroups, if you have Microsoft Win32s extensions, version 1.30 or higher. CyclePad requires a minimum of 12B. RAM but works better with 16B. RAM or more. Although CyclePad will run on a 486 CPU, we recommend a 90Mhz Pentium or faster for satisfactory performance. A complete installation requires approximately 10B. of hard disk space.

## Homework #1 due Oct 28th

### Problem 1.1 Turbojets for Cars

You are Director of New Engine Development for the Fjord Motor Car Company, and the CEO has just given you a mandate to develop a no-holds-barred sports car. Missam Motors has just introduced the Anaconda, a mid-engine design built around the Medusa, a sixteen cylinder engine with eight turbochargers, and the Vice-President of R&D for Fjord has decided that the only way Fjord can top this is with a gas-turbine-powered car. The new car, codenamed FireArrow, needs a specification for its engine. Unfortunately, Marketing has gotten involved, and as usual has bollixed things up. They want to make the following claims about the engine:

1. Compact and light-weight (enhances handling characteristics)
2. Most fuel-efficient gas-turbine possible (appeals to sensible side of buyers, enhances Fjord's reputation for cutting-edge engineering)
3. Achieves super-high compression (makes engine sound powerful)

Since you have to shoehorn this engine into a sports car the first claim clearly makes sense. However, you have a meeting with the Director of Marketing next week in which you'll have to explain why the other two claims are problematic.

To make your case create a simple air standard gas-turbine cycle in CyclePad. Use a cooler to represent the atmosphere. Since it's the atmosphere, choose air as the substance. An ambient pressure of around 1 bar will do nicely, and you can assume that the ambient temperature (i.e., the temperature both of the cooler and of the stuff entering the compressor) is 72°F, since Fjord expects to sell eight out of ten FireArrows in California. Using ultra-premium gasoline, you can achieve 1800°F in the burn-cans of the engine, which will heat the air entering the turbine to 1500°F. Assume this engine will develop $400hp_{net}$. Assume that all components are ideal.

Finally, choose a reasonable value for the pressure ratio across the compressor, say between 3 and 30.

Using the sensitivity analysis tool, determine the relationship between the compressor's pressure ratio and (a) the thermal efficiency of the engine and (b) the required mass-flow (which will in large part determine the size of the engine). From this information, decide on the optimal compression ratio for the compressor.

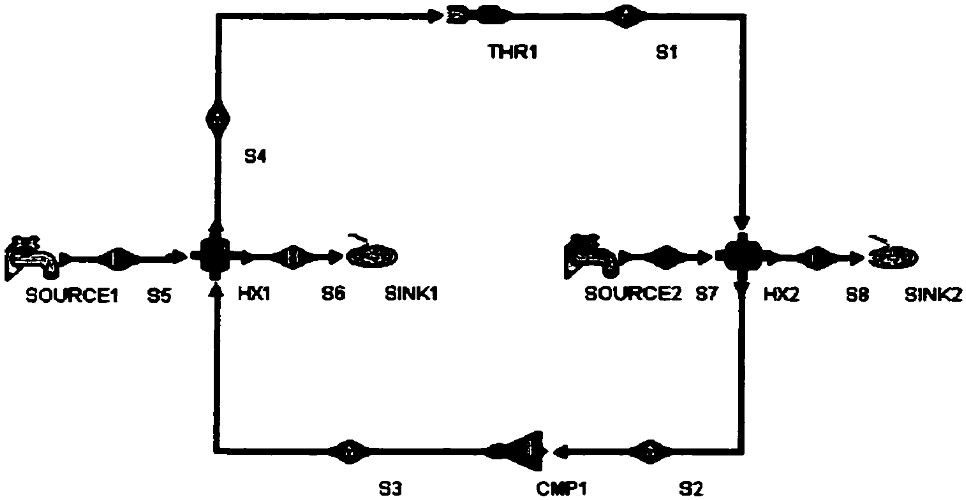
Having done so, develop a concise, qualitative argument for why this is the optimal compression ratio and why the Marketing Department should back off on its claims of fuel-efficiency and compression. (Choose **Design Notes** from the **Edit** menu and type your response there.)

## Problem 1.2 Putting the Ozone Back Where it Belongs

You are the Director of Product Development for ChillemGood, a leading manufacturer of refrigerators. An entrepreneur has approached the Director of Marketing with an idea for making a large refrigerator (meat locker?) that use all-natural, sparkling water in place of refrigerant-12. This entrepreneur claims that such a refrigerator would take less energy to operate. The President of ChillemGood wants your evaluation of the feasibility of this design.

Set up a simple vapor compression cycle using four components and R-12 as its working fluid in CyclePad. Assume that all components are ideal. The stuff in the refrigerator is to be kept at 42°F, and ambient room temperature is 72°F. The compressor is finicky about wet vapor, so make the stuff entering it saturated with a quality of 1. The stuff entering the throttle is saturated liquid. Assume a Volume flow of 0.25 $ft^3/s$ for the air entering the refrigerator and condenser. Try an initial pressure ratio (PR) of 5 for the compressor.

You will also need to make some assumptions about temperature. Assume that the refrigerator is cooling from 50F to 42F. You will also need to assume a temperature for the stuff entering the throttle that is above room temperature. Likewise, the stuff exiting the throttle needs to be cooler than 42C.




Then, as a separate system, set up another cycle using water as its working fluid. (be sure to save your R12 cycle!) In this cycle, do not specify a phase for the stuff entering the throttle. You may also want to retract your assumption about the compressor's pressure ratio before switching to water.

Answer the following questions in the **Design Notes** (under the **Edit** menu).

1. Compare the mass flow of the two cycles. Which requires more stuff?

2. Compare the pressure ratios. Which is larger?

3. How might the pressure ratio effect the type of compressor needed to build such a cycle?

4. Compare how much power is required by the compressor for the two cycles.

**Remember to e-mail both cycles!!!**

**Hints:**

* The m-dot may be *very* small for some working fluids, but still not be zero. Unfortunately, in attempting to keep the meter windows clean, CyclePad rounds things after a few digits for display. If m-dot looks like zero, but you are not getting an error, then click on the number and choose "Show full precision..." to see the actual value.

* The air volume flow rate cannot be the same both before and after the isobaric heat exchangers, otherwise the temperature won't change and you have zero heat transfer.

* The pressure of the air (both the cooled air and the cooling air) is atmospheric. We are just using a fan or something to blow air over the condenser or evaporator coils in the heat exchangers, so it's at atmospheric pressure.

## CyclePad Design Homework #2

The university is considering building its own small power plant to defray the increasing cost of electricity from the local utility and you are doing a preliminary feasibility study. Your current rough design is based on an air standard cycle with air as its working fluid, but some muckraker has told your boss that it gets less than 5 MW out of the 10 MW of heat input, and now he wonders if a better design could get the efficiency over 5.5 MW?

Use CyclePad to either modify a typical air standard cycle design (like the Brayton Cycle in CyclePad's library) or design a new cycle entirely to meet (or beat) this new efficiency goal. You may have to be clever: you probably can't get there by just tweaking numbers in the standard cycle; you will have to change cycle topology in Build Mode. Adding secondary cycles is fine.

Problem Constraints:

- Available working fluids are air and water.
- 10 MW of total external heat is available at no higher than 600 deg. C.
- Working fluids may be cooled down to 40 deg. C.
- Compressors and turbines can handle pressure ratios up to 10. Pumps up
- to 20.
- No saturated turbine outlet state can have quality lower than 90%.
- No more than three turbines may be used.
- Work elements are isentropic and adiabatic; heat elements are isobaric.

Questions

**Describe to the university, in layman's terms, how and why the features of your cycle enable the system to be more efficient.**

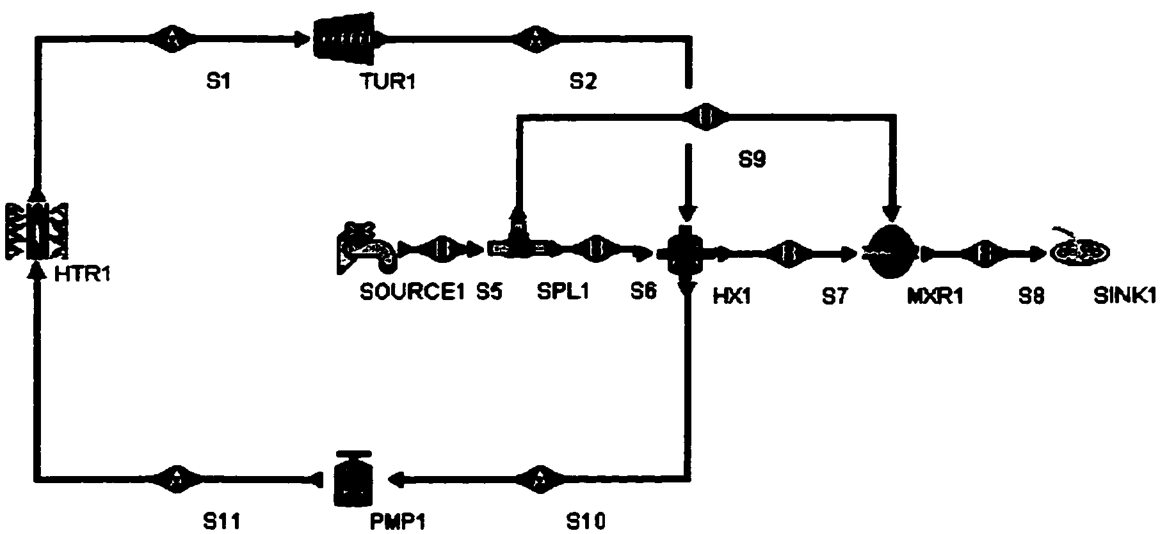
**Enter your description in design notes (under the "Edit" menu).**

# PROBLEMS OMITTED FROM 1997

**Making Sure it's not the Heat, but the Humidity...**

You have been charged with the construction of a new power plant to supply 100MW of baseload power to Ecoawareville, Montana. The Ecoawe river is really not much more than a stream, and during times of dry weather, its flow can decline to as low as 50,000 lbs/sec. However, it's the only source of cooling available for your power plant, so a site on the river has been selected and approved by the town council. Your job is to construct a vapor power cycle. The best turbine available has a shaft power of 100 MW, a maximum inlet temperature of 1000°F and maximum inlet pressure of 1200psi. The Ecoawe is fed by mountain runoff, so it never rises above 59°F, which makes it an ideal habitat for the rare back-flipping trout. A downstream temperature rise of more than 4.0°F (i.e. a temperature over 63F) will endanger this trout, and the citizens of Ecoaware will be swift to demand your head on a platter. Past experience has also shown that algae blooms occur if the discharged cooling water is greater than 75°F. (Assume atmospheric pressure for the river). The water at the turbine outlet must be at least 90% vapor to avoid turbine damage.

Set up a simple vapor cycle that uses a heat-exchanger as its condenser. Model the river using a source and a sink and use a splitter and direct a flow of cooling water through the heat-exchanger. You will need to specify that the flow fraction of the stuff exiting the source is 1.



Report on the highest thermal and Carnot efficiency you can achieve given the above constraints and on the relationship between the turbine outlet pressure and its waste heat discharge.

Hints:

* The working fluid exiting the heat exchanger should be a saturated liquid, just as it would for a Rankine cycle.

* You can't set the temperature both at S7 and S8. You have to do S7, then make sure S8 isn't exceeded afterwards.

* It's easiest to set P at the turbine outlet, then check that the quality spec is met. You can only do sensitivity analyses with assumed values as the independent varables, and you probably want to do one of those with P as the independent variable.

**Power from the Ocean**

You are the Chief Engineer for Warza, Inc, a major builder of power plants, and the City of San Diego has asked you to investigate the feasibility of building a Ocean Thermal Energy power plant. The Pacific off the San Diego coast has a surface temperature of 27°C and a temperature at a depth of 600 ft of 5°C. The plant should generate 100MW of power. Assume that you need at least a 3°C difference for reasonable heat transfer rates between the sea water and the working fluid.

Using a simple vapor power cycle (ie, only use four components, a heater, a turbine, a cooler, and a pump), investigate at least two different working fluids (R12, R134a, R22 or ammonia).

Hints:

* At the turbine inlet, the stuff should be saturated vapor.

* Pick a turbine outlet temperature such that T is a little bit larger than 8C. To do this you can assume a T of 8C to determine what the saturation pressure

is for that temperature (P-sat). You will want to use a pressure slightly greater than P-sat @ 8C.

* You may need to equate the outlet-T of the pump with the inlet-T. (This is a bug with the lookup feature).

* Remember that the *ocean* is at 5 and 27 degrees C, the working fluid only gets within 3 degrees of these extremes.

* This problem tempts you to draw several cycles in the same design and do all of the working fluids in the same place. Don't do it. Use a separate design file for each working fluid. (You can just change the working fluid and save it under a different name.)

Answer these questions in the Design Notes:

1. Make a case for a particular substance, taking into consideration the size of the equipment required and the potential environmental danger it would pose.

2. **What is the required mass flow for each substance? Compare this to the standard Rankine cycle (from the CyclePad library).**
3. **Also compare the efficiencies with the standard Rankine cycle. How and why do they differ?**

   **Remember to email both cycles!!!**

APPENDIX D

# NU CYCLEPAD HOMEWORK ASSIGNMENTS:

# THERMODYNAMICS I

## Chapter 2

**Problem CP1 (based on 2-46)**

A rigid tank with a volume of $2.5m^3$ contains 5kg of saturated liquid-vapor mixture of water at 75°C. Now the water is slowly heated.

Determine the temperature at which the liquid in the tank is completely vaporized.

How did CyclePad arrive at the value of 104.7°C for $T_2$?

What key assumption (that you made) allowed CyclePad to determine the final specific volume (v)?

Draw a P-v diagram for this process.

Now change the heating process to a constant-pressure process.

Could this process take place in a rigid tank? Why or why not?

Draw a P-v diagram for this second process.

**Problem CP2 (based on 2-69)**

The pressure in an automobile tire depends on the temperature of the air in the tire. When the air temperature is 25°C, the pressure gage reads 210 kPa.

If the volume of the tire is 0.025 $m^3$, determine the pressure rise in the tire when the air temperature in the tire rises 50°C.

If the volume of the tire is 0.025 $m^3$, determine the pressure rise in the tire when the air temperature in the tire rises 50°C.

Also, determine the amount of air that must be bled off to restore pressure to its original value at this temperature. Assume the atmospheric pressure to be 100 kPa.

How is CyclePad able to calculate the pressure when T is 50°C ?

Chapter 3

**Problem CP3** (based on 3-35E)

A frictionless piston-cylinder device initially contains 12 lbm of superheated water vapor at 60 psia and 500°F. Steam is now cooled at constant pressure until 70 percent of it, by mass, condenses.

Determine the work done during this process.

(How much work would have been done if this process was isochoric? Why? --- bug in Cp doesn't work yet, try again once we fix the bug)

What formula would you use if you were to solve this problem by hand?

**Problem CP4** (based on 3-46)

A piston-cylinder device with a set of stops contains 10 kg of refrigerant 134a. Initially, 8 kg of the refrigerant is in the liquid form, and the temperature is -8°C. Now heat is transferred slowly to the refrigerant until the piston hits the stops, at which point the volume is 400 L.

Determine the temperature when the piston first hits the stops. Hint: pick final phase saturated.

Explain the temperature difference between the start and stop.

Determine the work done during this process.

Show the process on a P-v diagram

Use sensitivity analysis to examine the relationship between the T at the outlet and the outlet volume. (Bug right now: need to fix this feature)

Chapter 4

**Problem CP5** (based on 4-30)

Steam enters an adiabatic turbine at 10MPa and 400°C and leaves at 20kPa with a quality of 90 percent.

Neglecting the changes in kinetic and potential energies, determine the mass flow rate required for a power output of 5 MW.

How does the required mass flow change if we alter the dryness at the outlet? Why? (hint: do a sensitivity plot)

**Problem CP6** (based on 4-58)

Refrigerant 134a at 800 kPa, 70°C, and 8kg/min is cooled by water in a condenser until it exits as a saturated liquid at the same pressure. The cooling water enters the condenser at 300 kPa and 15°C and leaves at 30°C at the same pressure.

Determine the mass flow rate of the cooling water required to cool the refrigerant.

Where does the First Law apply to this problem? (hint look in subcycle A and B under the Cycle Properties menu or look at the Heat Exchanger properties)

**Problem CP7** (based on 4-16)

You will need to make sure *CyclePad* is considering velocity to do this problem. Do this in the Edit □ Preferences menu under the "Advanced" settings.

Steam at 3 MPa and 400°C enters an adiabatic nozzle (throttle) steadily at 40 m/s and exits at 2.5 MPa and 300 m/s.

Determine the exit temperature.

The ratio of inlet to outlet areas. (Hint: assume outlet area = 1 $m^2$)

Do the same problem with air as the working fluid. What does the different outlet temperature of air tell us about the heat capacity of air compared to that of steam?

Chapter 5

no problems for Chapter 5

Chapter 6

**Problem CP8** (based on 6-31)

1 kg/s of refrigerant-134a enters the coils of the evaporator of a refrigeration system as a saturated liquid-vapor mixture at a pressure of 200 kPa. The refrigerant absorbs 120 kW of heat from the cooled space, which is maintained at -5°C, and leaves as saturated vapor at the same pressure.

Hint: This system can be modeled as a heater.

Do this problem using the assignment feature of *CyclePad*. This assignment will be called CP8.PRB and can be opened using the "Open Assignment Problem" of the open dialog or by going to the Assignments menu bar item and choosing "Open Assignment Problem". The file and further instructions can be downloaded from the web at
http://www.qrg.ils.nwu.edu/software/cyclepad/ME-B20.htm

Determine the total entropy change of the refrigerant.

Determine the total entropy change of the cooled space.

ANS: -.4475 kJ/K for environment

Determine the total entropy generation for this process.