ACTIVE LEARNING IN

TRANSPORTATION ENGINEERING EDUCATION

by

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ABSTRACT

The objectives of this research were (1) to develop experimental active-based-learning curricula for undergraduate courses in transportation engineering and (2) to assess the effectiveness of an active-learning-based traffic engineering curriculum through an educational experiment. The researcher developed a new highway design course as a pilot study to test selected active-learning techniques before employing them in the traffic engineering curriculum. Active-learning techniques, including multiple-choice questions, short problems completed by individual students or small groups, and group discussions, were used as active interludes within lectures. The researcher also collected and analyzed student performance and attitude data from control and experimental classes to evaluate the relative effectiveness of the traditional lecture (control) approach and the active-learning (experimental) approach.

The results indicate that the active-learning approach adopted for the experimental class did have a positive impact on student performance as measured by exam scores. The students in the experimental class also indicated slightly more positive attitudes at the end of the course than the control class, although the difference was not significant. The author recommends that active interludes similar to those in the experimental curricula be used in other courses in civil engineering.

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I. INTRODUCTION

Engineering is an applied science. According to the 2003-2004 Accreditation Board for Engineering and Technology (ABET) requirements for engineering programs, graduates of such programs must demonstrate "an ability to apply knowledge of mathematics, science, and engineering" (criterion 3a) and "an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice" (criterion 3k).*[1]* An engineering graduate who cannot apply what he or she has learned in school to actual practice is of little use to an employer. In theory, the best way to learn to apply one's knowledge is to acquire or learn it in a realistic context. One method to encourage students to apply their knowledge to "real-life" problems is to include opportunities for such application within the curriculum. For example, students at Northeastern University alternate semesters between the classroom and "cooperative education" at engineering companies, and students at Worcester Polytechnic Institute complete a series of projects in addition to coursework. Knowledge that has not been acquired, however, cannot be applied. Engineering courses should provide students with the necessary knowledge. The knowledge, techniques, and skills referred to in the ABET requirements must be learned and understood satisfactorily in order to be able to use them in practice.

In current educational theory, learning is seen as an active process, in which students must interact with information in order to understand it.*[2, 3, 4]* In a typical engineering course, the "active" part of learning takes place outside of the classroom, in the form of solving homework problems or conducting course projects, while the time in the classroom is more passive, in the form of listening to lectures. Thus, the students interact with the course material - and gain understanding of it – primarily in the absence of the instructor.

Teaching methods have been explored in previous research that encourage students to interact with course material inside the classroom, under the supervision of the instructor. In past studies, such methods, termed "active learning methods," appeared to result in improved understanding and more positive student responses to course material, compared to lectures alone. The relevant literature is discussed in more detail in

Chapter II of this document.

Although a number of researchers have experimented with active learning methods, most of them focused on courses in the sciences and social sciences, rather than engineering. Disciplinary differences may affect the applicability and effectiveness of the teaching methods. Most of the available studies also lack thorough assessment of the effectiveness of the teaching methods. In many cases, several changes were made to a course simultaneously, which complicates analysis of any one factor.

The objectives of this research were (1) to develop active-learning-based curricula for undergraduate transportation engineering courses and (2) to assess the effectiveness of the experimental traffic engineering curriculum through an educational experiment. Selected active techniques were tested in the experimental curriculum and their effectiveness compared with that of the lecture approach. The results were assessed both quantitatively in terms of the students' mastery of the course objectives and their attitudes toward the course and area of study.

The courses used to conduct this research were undergraduate transportation engineering courses at Worcester Polytechnic Institute (WPI). Transportation engineering is an area of study within civil engineering that includes both abstract theories and practical skills. Students need to learn the basic concepts and vocabulary used to understand and describe traffic, and they need to be able to apply these concepts to perform engineering studies. Traditionally, undergraduate students have been taught about transportation engineering through lectures and readings. Some courses include separate lecture and laboratory sessions, while others are lecture-based with assigned activities outside of class. Active-learning methods within the classroom are a different approach that had not been tested in this context.

The results of this project will contribute to the knowledge base of activities that enhance student learning in undergraduate engineering courses, as well as improving the undergraduate education of civil and transportation engineers at WPI and other universities.

II. Literature Review

One of the first tasks in this project was to identify relevant sources of information for use in defining the project focus and developing an experimental curriculum. This chapter reviews the available literature in the areas of learning theory, active learning, and assessment.

2.1. Learning Theory

Epistemology, or the study of knowledge, encompasses a broad range of theories and topics. This section will focus on some current theories about learning. It is not intended to be a thorough review of the literature in this area, but to provide an adequate background for understanding the context of this dissertation.

2.1.1 Constructivism

Constructivism, or the constructivist view of learning, is that students construct their own knowledge as they attempt to make sense of information or environments.*[2]* Unlike some other theories of learning such as behaviorism, constructivism says that knowledge cannot be simply transferred from teacher to learner. Learners must actively interpret and develop understanding from the information given to them.*[3]* Their understanding of the new information is built upon their prior knowledge. Donald describes the constructivist view in this way: "The view that knowledge is constructed carries dangers – it could be interpreted to mean that truth is dead and therefore chaos reigns. A more measured perspective is that we each construct our own understanding of the large bodies of organized public knowledge that the disciplines represent."*[4]* In engineering, "understanding occurs as a result of joining concepts to actions."*[4]* Most relevant to the college classroom, social constructivism asserts that "learners arrive at what they know mainly through participating in the social practice of the classroom and through course projects and assignments."*[3]* These activities could include discussions, group projects, or group work on homework assignments, depending on the course.

2.1.2 Kolb's Learning Cycle

Kolb developed a four-step model learning cycle for complete, long-term learning. The steps are termed concrete experience, reflective observation, abstract conceptualization, and active experimentation. Courses that include all these steps should result in better retention of material by the students.*[2, 5]* "Students who are guided through the learning cycle are exposed to a wider variety of learning experiences and increased opportunities for self discovery and independent thinking."*[6]* Kolb also developed a learning style inventory based on the idea that people have different learning styles, or preferences for different steps in the learning cycle. Kolb's theory, known as "experiential learning theory," has been studied and written about extensively, but its effects on learning have been inconclusive, largely due to lack of data. Several meta-analyses in the 1990s concluded that a majority of the studies in the literature up to that time support the use of experiential learning theory and Kolb's learning style inventory.*[7]* Harb comments that "although we have observed positive results from the use of the learning cycle in the engineering classroom, it is difficult to make a quantitative evaluation of the effectiveness of these techniques."*[6]* This problem is not unique to Kolb's learning cycle, but seems to be a common issue in assessing learning theories.

McCarthy combined Kolb's learning cycle with other learning theories such as right and left-brain dominance and learning styles to develop a modified learning cycle known as the 4MAT system.*[8]* She focused on the use of the learning cycle in teaching. Harb *et al. [6]* and Todd *[9],* among others, have applied this system to engineering classes. It is represented by four quadrants as shown in Figure 2.1. An instructor may begin by providing students with a "concrete experience," such as a hands-on demonstration. In quadrant one, moving from concrete experience to reflective observation, the instructor introduces the material and helps students understand why learning the material is important. The students next move from reflective observation to abstract conceptualization, learning concepts through lectures or other activities, in quadrant two. "Information transfer (quadrant two) remains an essential function of the engineering professor."*[6]* In quadrant three, they move from abstract conceptualization to active experimentation, actively doing something with the concepts to learn how they work or how to solve problems. The instructor acts as a coach, providing a guided learning experience for the students. Finally, the students apply what they have learned to new problems and "real life," or concrete experience, in quadrant four.*[2, 6]*

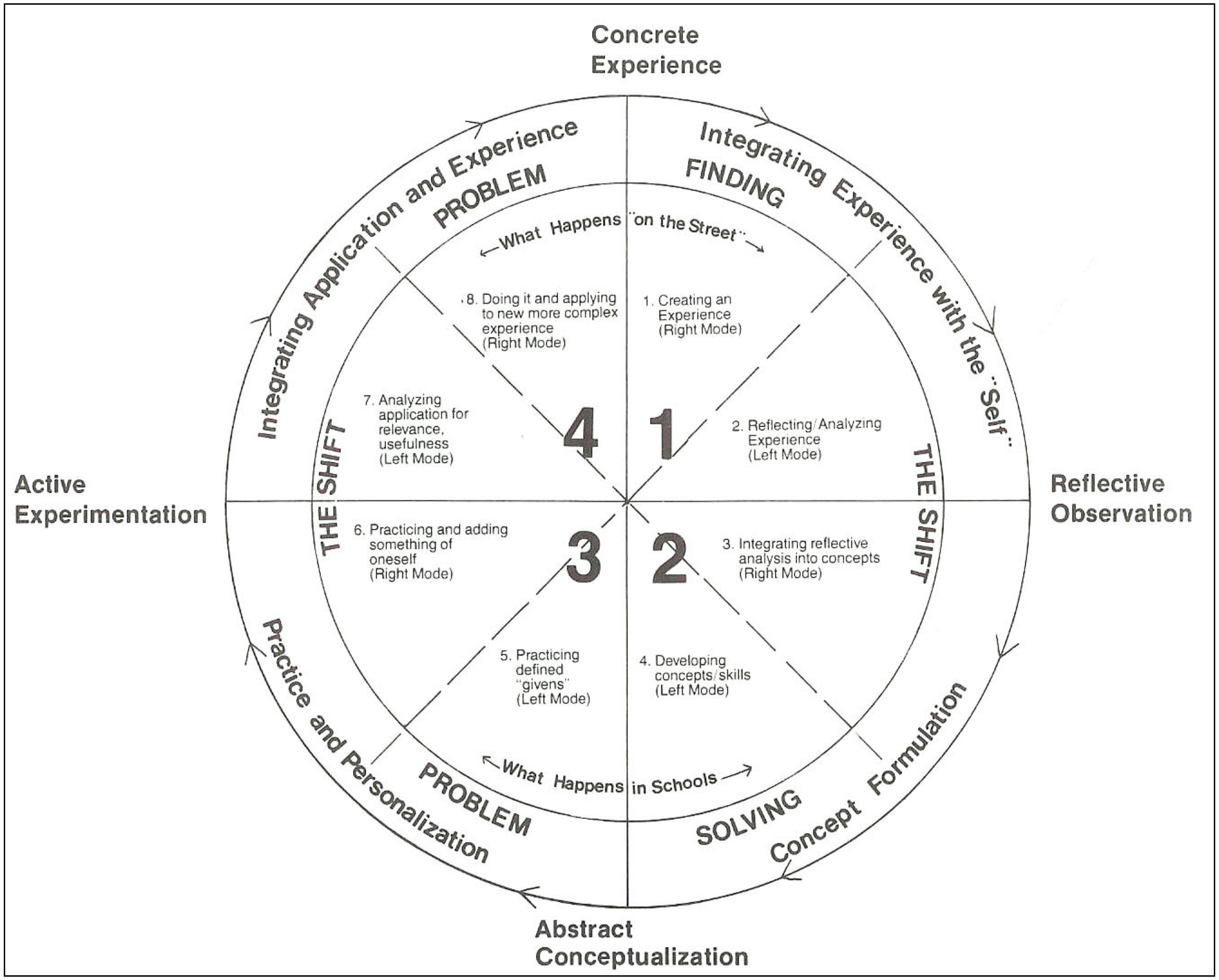

Figure 2.1. The 4MAT System Model.*[8] Reprinted with permission of Bernice McCarthy.*

2.1.3 Thinking Processes

Donald has described a number of thinking processes that are expected and developed in higher education, shown in Table 2.1. This model was developed "by creating a comprehensive list of thinking processes from the postsecondary literature, then having instructional experts group the definitions on the basis of similarity and describe the basis of their grouping."*[4]* These processes of thinking and learning are emphasized and valued differently in different disciplines. She defines a discipline as "a body of knowledge with a reasonably logical taxonomy, a specialized vocabulary, an accepted body of theory, a systematic research strategy, and techniques for replication and validation."*[4]*

Donald's discussion of disciplinary differences treats all the branches of engineering together due to their similarities. All the categories of thinking processes in Table 2.1 are important in engineering courses and generally receive attention. Engineering is comprised primarily of problem solving and design. Descriptive and selective thinking processes are important because students must learn to handle open-ended problems in which there may be either a great deal of information or missing information. Problem solving makes extensive use of representation, which includes diagrams, formulas, laws, and designs.*[4]* Chase and Chi found that problem-solving skills require "extensive practice to build up [a] long-term knowledge base" on which to draw in solving a particular problem. This knowledge base includes "lexical knowledge," i.e., patterns or lexicons, and procedural knowledge, a set of strategies or procedures for use with the patterns. "A fast action pattern recognition system … greatly reduces processing load and serves as a retrieval aid for alternative courses of action."*[10]* Inference is used during problem-solving to think about the implications of facts or calculations.*[4]*

Design focuses on synthesis and verification. Engineering programs attempt to "produce creative, independent, flexible, and critically thinking individuals" who can both solve problems and design solutions.*[4]* Donald notes that students in engineering programs are trained to synthesize: "students start out with guided synthesis, rather than self-generated synthesis, and their labs are intended to nurture these skills…. students have the design process modeled for them and then are given more leeway with greater responsibility in projects. Projects are the primary means of developing synthesis."*[4]* Verification is critical because (1) engineering problems often require assumptions and approximations and (2) professional liability encourages engineers to limit risk as much as possible.*[4]*

Table 2.1. Thinking Processes in Higher Education.*[4] Reprinted with permission of John Wiley & Sons, Inc.*

DESCRIPTION (PS, SM)	Delineation or definition of a situation or form of a thing.
Identify context (E)	Establish surrounding environment to create a total picture.
State conditions	State essential parts, prerequisites, or requirements.
State facts	State known information, events that have occurred.
State functions	State normal or proper activity of a thing or specific duties.
State assumptions (CT)	State suppositions, postulates, or propositions assumed.
State goal	State the ends, aims, objectives.
SELECTION (PS)	Choice in preference to another or others.
Choose relevant information (E)	Select information that is pertinent to the issue in question.
Order information in importance	Rank, arrange in importance or according to significance.
Identify critical elements	Determine units, parts, components that are important.
Identify critical relations	Determine connections between things that are important.
REPRESENTATION (PS)	Description or portrayal through enactive, iconic, or symbolic means.
Recognize organizing principles	Identify laws, methods, rules that arrange in a systematic whole.
Organize elements and relations	Arrange parts, connections between things into a systematic whole.
Illustrate elements and relations	Make clear by examples the parts, connections between things.
Modify elements and relations	Change, alter, or qualify the parts, connections between things.
INFERENCE (E, H, CT, PS)	Act or process of drawing conclusions from premises or evidence.
Discover new relations between elements	Detect or expose connections between parts, units, components.
Discover new relations between relations	Detect or expose connections between connections of things.
Discover equivalences	Detect or expose equality in value, force, or significance.
Categorize	Classify, arrange into parts.
Order	Rank, sequence, arrange methodically.
Change perspective	Alter view, vista, interrelations, significance of facts or information.
Hypothesize	Suppose or form a proposition as a basis for reasoning.
SYNTHESIS (PS)	Composition of parts or elements into a complex whole.
Combine parts to form a whole	Join, associate elements, components into a system or pattern.
Elaborate	Work out, complete with great detail, exactness, or complexity.
Generate missing links	Produce or create what is lacking in a sequence; fill in the gap.
Develop course of action	Work out or expand the path, route, or direction to be taken.
VERIFICATION (E, H, CT, PS, SM)	Confirmation of accuracy, coherence, consistency, correspondence.
Compare alternative outcomes	Examine similarities or differences of results, consequences.
Compare outcome to standard	Examine similarities, differences of results based on a criterion.
Judge validity	Critically examine soundness, effectiveness, by actual fact.
Use feedback	Employ results to regulate, adjust, adapt.
Confirm results	Establish or ratify conclusions, effects, outcomes, products.

E: expertise; H: hermeneutics; CT: critical thinking; PS: problem solving; SM: scientific method

2.1.4 Learning Engineering

According to Donald, "engineering programs … provide a learning environment that is in marked contrast to many other undergraduate programs."*[4]* Differences among areas of study and the ramifications of these differences have been the focus of much research and discussion.

Biglan studied a number of disciplines and described engineering (i.e., civil, mechanical, ceramic, and nuclear engineering), science (e.g., astronomy, physics, and chemistry), math, computer science, and agriculture (i.e., horticulture, dairy science, and agronomy) disciplines as "hard." A hard discipline is "logically structured … and has an acknowledged methodology" or paradigm, while a "soft" discipline is characterized by a lack of consensus about content and method.*[4, 11]* According to Biglan, extremely soft disciplines include humanities and education areas. Social sciences and business areas are also considered soft, but less so; he characterized these as "fields that strive for a paradigm; but have yet to achieve one."*[11]* Biglan also distinguished between "pure" and "applied" disciplines. A pure discipline focuses on principles and theories, while an applied discipline is concerned with application to practical problems. He described education, engineering, and accounting/finance disciplines as strongly applied and also considered agriculture and computer science applied. Pure disciplines include the "physical sciences, mathematics, social sciences, languages, history, and philosophy."*[11]* Figure 2.2 summarizes these disciplinary attributes. The horizontal axis of the figure represents the hard-soft nature of the discipline, where the hardest disciplines are located farthest to the left. The vertical axis represents the pure-applied nature, where the purest disciplines are located closest to the bottom. Note that the engineering, agriculture, and computer science disciplines are the only areas of study that are both hard and applied; engineering and agriculture are the most similar in terms of these characteristics.

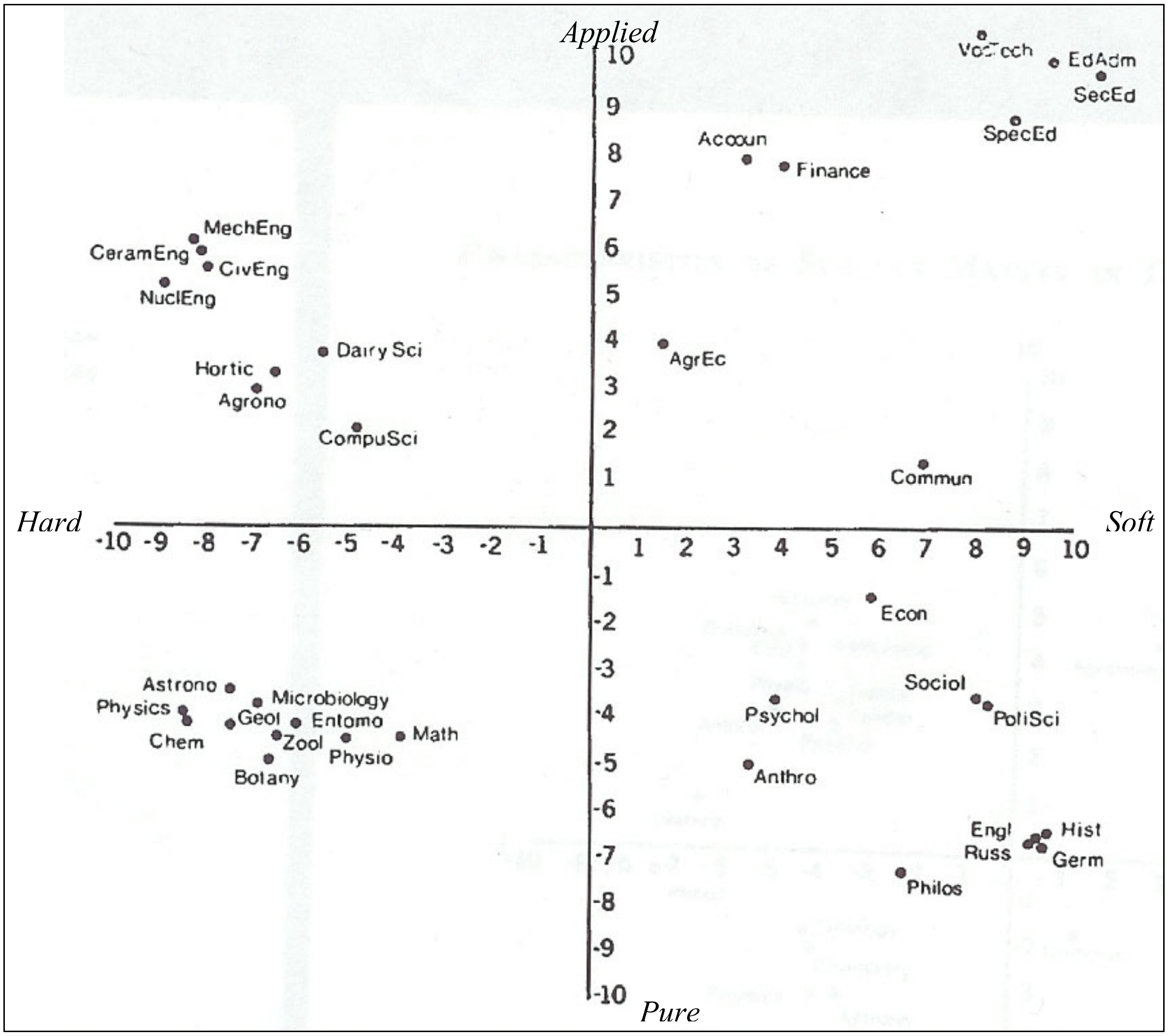

Figure 2.2. Characteristics of Disciplines: Hard v. Soft, Pure v. Applied.*[11] Copyright 1973 by the American Psychological Association. Reproduced with permission.*

Much research in higher education has focused on the sciences. These disciplines do share some similarities with engineering courses, but as Biglan's findings imply, they have some differences as well. As noted in Section 2.1.3, engineering includes problem solving and design. These abilities require a familiarity with and understanding of many concepts from mathematics and physical science courses, but also a number of thinking processes that are not emphasized in such courses. "Throughout their training, [engineering] students are being inducted into a profession that values hard thinking applied to unstructured problems."*[4]* Inference is important in chemistry and biology as in engineering, but in these sciences it is in conjunction with inductive rather than deductive reasoning. Physics is structured and process-oriented like engineering, but does not emphasize descriptive and selective thinking processes.*[4,5]* The physical sciences are also oriented primarily toward declarative knowledge, while engineering courses are concerned with procedural knowledge. Declarative knowledge includes facts and principles; procedural knowledge includes "knowledge about our knowledge and how to apply it." One professor describes it this way: "the real value in engineering is being able to think and apply these fundamentals to new problems you have not seen before…. If the answer is already known, no one is going to pay someone to answer it again."*[4]*

Disciplines may also be characterized by the objectives of their courses. The IDEA Center at Kansas State University has created student rating-of-instruction forms that ask about progress on twelve general course learning objectives, intended to be applicable to a broad range of disciplines. The course instructors provide information about the importance of each of the learning objectives to the course. According to an analysis of recent course results, the four objectives most often identified as "essential" or "important" by instructors of engineering courses were "gaining factual knowledge" (objective 1); "learning fundamental principles, generalizations, and theories" (objective 2); "learning to apply course material" (objective 3); and "developing specific skills, competencies, and points of view needed by professionals in the field most closely related to this course" (objective 4).*[12]* Over eighty percent of the instructors chose each of the first three objectives as essential or important, and 73 percent chose the last objective as essential or important. Instructors in a number of disciplines chose these four objectives, as shown in Table 2.2. The entire list of objectives is not shown here for space and clarity.

Table 2.2. Disciplinary Selection of Learning Objectives (Percent of Classes Selecting Objectives as Essential or Important) on IDEA Student Ratings.*[12]*

Discipline	*Objective*			
	Factual knowledge	*Principles & theories*	*Apply course material*	*Specific skills*
Accounting	96	91	83	75
Adm/Management	80	82	87	67
Art	63	61	57	68
Biology/Life Science	93	90	64	47
Business	85	80	83	65
Chemistry	91	89	81	52
Computer Science	93	77	80	83
Design/Applied Art	82	80	83	86
Economics	91	96	84	33
Education	78	76	83	84
Engineering	83	82	88	73
English Literature	36	35	48	28
Fine/Applied Arts	75	75	69	74
Foreign Language	77	50	38	39
History	94	56	43	25
Health Professions & Related Sciences	83	75	82	74
Liberal Arts/Science	62	61	66	23
Math/Statistics	94	94	92	46
Music	70	57	45	66
Nursing	77	75	88	77
Philosophy	52	82	62	15
Physical/Health/ Safety Education	89	76	77	60
Physics	89	96	83	41
Political Science	84	83	62	28
Psychology	87	87	75	43
Religion	81	79	55	29
Sociology	87	82	70	35

The choice of "learning to apply course material" by math, physics, and chemistry instructors appears to contradict Biglan's characterization of these as pure disciplines, but the instructors may be interpreting the IDEA objective differently from Biglan's definition. Disciplines in which the same objectives as those in engineering were chosen by over 70 percent of instructors were: accounting, computer science, design/applied art, education, health professions, and nursing.*[12]* According to an IDEA group summary report for "agricultural business and production and agricultural sciences," the agriculture-related courses also shared similar results, with 87 percent of instructors choosing objective 1, 79 percent objective 2, 71 percent objective 3, and 68 percent objective 4.*[13]* The dissimilarities among these disciplines implies that the objectives are, as they are designed to be, widely applicable regardless of discipline, due to the vague way in which they are worded.

2.2. Active Learning

Most engineering courses in the U.S. are taught primarily in a lecture mode, although a number of professors use discussion or lab sessions to complement the lectures. Of 3276 engineering courses rated using the IDEA forms between December 2001 and August 2003, instructors reported using "lecture" as the primary instructional approach in 66 percent and as the secondary approach in 13 percent. "Laboratory" was the secondary approach in 16 percent of the classes, and "discussion/recitation" was the secondary approach in 19 percent.*[13]* Teaching approaches in other countries may differ. For example, a recent study of engineering professors teaching first-year courses at a small engineering college in the Netherlands found that about 25 percent of the professors had a "teacher-centered conception," in which the teacher was viewed as an expert who "imparts information to students," and 67 percent had a "student-directing conception of teaching." The student-directing view was characterized by a desire to "stimulate and support student learning." The professors planned and controlled a variety of learning activities to engage the students and "cover a fixed amount of subject matter." The student-directing conception of teaching retains much instructor control but involves the students more actively than lecturing alone.*[14]*

The Kolb learning cycle model emphasizes the need for students to interact with course content in different ways in order to understand and retain it. "Students are … more likely to internalize, understand, and remember material learned through active engagement in the learning process."*[15]* The effectiveness of a more active approach to learning, referred to as active learning, has been demonstrated in numerous research studies. Teaching methods promoting active learning are "instructional activities involving students in doing things and thinking about what they are doing."*[16]* Active learning techniques have been used effectively in a number of disciplines, including in several types of engineering courses, to improve student attitudes and learning. These techniques vary widely, from using flashcards and "muddiest point" surveys to fully student-centered studio classes. What they have in common is that students must take a more active role in the learning process than simply listening and taking notes during a lecture. In most cases, the focus is on in-class active methods rather than activities outside of class.

2.2.1 Active Learning Studies

Active learning techniques have been used in many disciplines, including the sciences, management, computer science, and engineering. Some examples are the use of in-class cooperative learning exercises in a management course, and discussions, surveys, and group activities in an upper-level computer science course.*[17, 18]* In most cases, the focus of the articles is the methods used and the qualitative responses of the students, without much attention to quantitative assessment of the results. Since most of the instructors were trying to improve a course, they often included several methods and changed exams and even course objectives. This makes the effectiveness of the individual methods difficult to assess. Bonwell commented in 1991 that "most published articles on active learning have been descriptive accounts rather than empirical investigations," and it does not appear that this situation has changed significantly.*[16]* Miller and Cooper did attempt to assess student learning by giving an identical exam to two parallel classes, one traditional and one non-traditional, but a number of data-skewing factors complicated the analysis.*[19]*

Undergraduate science courses, particularly basic and non-major courses, were the subject of many of these active learning studies. For example, Miller and Groccia found that cooperative learning compared favorably with the traditional lecture approach for introductory biology, in terms of "student satisfaction, the ability to find information on one's own, the acquisition of factual knowledge, and the ability to work with others."*[20]* McClanahan and McClanahan found that using active learning techniques in a non-majors biology class helped the students "focus on and understand key concepts of the course."*[21]* Other studies were performed in basic courses in engineering, such as mechanics and introductory design.*[19, 22]*

Some of the studies focused on particular methods, such as Mehta's "flashcard" method *[23]* or studio approaches, *[22, 24, 25]* or on combinations of methods.*[19, 26, 27, 28, 29]* These methods are discussed in more detail in Section 2.2.3. In general, the student response to these methods was positive. For example, all the students in Mehta's study rated his method as "effective" or "very effective" in improving their learning in the classroom.*[23]* As Felder points out in a summary of one study, "the results suggest that active and cooperative learning methods facilitate both learning and a variety of interpersonal and thinking skills, and that while these methods may initially provoke student resistance, the resistance can be overcome if the methods are implemented with care."*[30]* In general, the literature suggests that active-learning methods are probably effective, but data are lacking.

2.2.2 Active Learning Experiments in Engineering Education

The content of engineering courses places some constraints on the applicability of active learning techniques. For example, unlike in humanities and social sciences, "much of the basic content of engineering courses is not a matter of opinion," and the student's reflections or emotional reactions are not relevant.*[27]* Unlike in the sciences, hands-on laboratory experiments are often inappropriate or impractical. This section describes active learning experiments that have been conducted in engineering courses.

Felder and others wrote a number of papers about a longitudinal study in chemical engineering. In 1990-1991, he taught five consecutive undergraduate chemical engineering courses using cooperative learning and other methods designed to address different learning styles. One of those instructional methods was “extensive active and cooperative learning.”*[30]* Each class session included lecture, problem-solving, and small group exercises. The group exercises consisted of a variety of activities in two to four-person groups, such as recall or response questions, parts of problems, derivations, critical thinking questions, or question generation. Most of the exercises were five minutes or less, although some were longer activities. In general, students responded positively to Felder’s methods. The student ratings were “consistently and overwhelmingly positive,” and their grade distribution was “markedly skewed toward higher grades.”*[27]* The students in the experimental classes “outperformed the comparison group on a number of measures, including retention and graduation in chemical engineering.”*[30]* It is important to note, however, that Felder was not assessing active learning alone, but in conjunction with other course improvements, including “multidisciplinary problem and solution exercises” and “criterion-referenced grading.”*[30]*

Blackwell used group discussion techniques in an upper-level course, ”Biomedical Electrical Systems.” Student groups of four or five chose four topics from a list, read and discussed articles, answered questions, and completed an essay and problem exam. This method allowed the class to cover material of interest to each group of students in a collaborative fashion. The instructor found that the average grades in the class improved by 13% and classroom participation increased.*[31]*

Todd developed an introductory course in manufacturing processes using a variety of active techniques designed to appeal to all of Kolb’s learning styles. The techniques included group presentations, lab work, team projects, and case studies. No assessment of the results was provided.*[9]*

Several faculty at Harvey Mudd College experimented with a first-year course, “Introduction to Engineering Design.” While always a project-based course, it was redesigned for two semesters as an engineering design studio course in which the students essentially taught themselves in groups through design problems, with the instructors acting as facilitators and resources. They concluded that the studio method was effective in teaching design, but the students needed clear communication about course expectations and grades since the format was unfamiliar to them.*[22]*

Faculty at the University of Washington developed new course materials to incorporate design into a sophomore-level engineering mechanics of materials course that had previously had no design component. These materials included hands-on activities, computer simulations, and multimedia tools. The materials were used in an experimental section with a new course approach involving design projects, group work, and competency exams. The students completed open-ended group design projects, resulting in written reports and oral presentations. There was no significant difference between the performance of a "traditional" section of the course and this experimental section on an identical final exam, and student responses to the new approach were positive. The authors concluded that design concepts were successfully integrated into the mechanics course without loss of effectiveness or content coverage.*[19]*

Faculty in MIT's Aeronautics and Astronautics Department have increasingly adopted active learning techniques within a lecture-based, sophomore-level course, "Unified Engineering." Student responses to the teaching methods on mid-term and end-of-semester evaluations "reflected an overall positive attitude towards the active learning techniques." They gave high ratings to the effectiveness of in-class exercises, such as concept tests and "turn-to-partner" exercises, and commented on the positive social dynamics within the class.*[28]* No assessment of student performance was discussed in the article, which focused on the process of adopting these teaching methods.

Koehn discussed the use of collaborative learning in a civil/construction engineering course over ten years. The course used a combination of lectures, student seminars, and a team design project. Results of student surveys indicated that students preferred "thought-provoking questions and discussion" and "group interaction" to the traditional teaching methods, although discussion was difficult to initiate at times. The students appeared to have accepted and enjoyed the collaborative learning activities.*[32]*

In 2002, a senior-level Electrical Engineering course at Worcester Polytechnic Institute that had previously involved lecture and lab sessions was offered in a new studio format. The studio format included 25-minute lectures followed by either a lab exercise or a simulation. Student feedback was positive, and initial results suggested that students learned the material covered in the studio sections of the class better than they learned the material covered in the lectures.*[24]*

2.2.3 Specific Techniques

Active learning can be accomplished inside or outside the classroom. Out-of-class activities usually consist of homework or project assignments. Where instructors do not explicitly provide activities, students often create their own, such as working on homework in informal groups. In most cases the instructor has no supervision or control over such activities.

Researchers have also developed or used a variety of techniques inside the classroom to encourage active learning. The many in-class active learning techniques found in the literature can be grouped into three categories based on the predominant teaching format used: *active interludes*, which are brief student activities within a lecture; *class activities*, such as discussions, that occupy a substantial portion of the class session; and *student-centered classes*, which are primarily based on self or peer instruction.

An active interlude can be any brief activity included before, within, or after a lecture. This format has also been described as an “enhanced lecture.”*[15]* The usual purposes of an active interlude are to maintain or recapture student attention and engagement, to provide feedback about student comprehension, or to provide feedback about instructional methods. The simplest technique is to pause for approximately two minutes at intervals during the lecture, to allow students to think about what has been presented.*[16, 33]* Extensions of this idea include “reflective pauses,” in which students answer a question or solve a problem related to the lecture,*[34]* and having students compare notes during longer pauses.*[33]* Students can also be involved directly in the lecture through brief, interactive demonstrations *[16, 28, 35]* or working at the blackboard.*[33]* Feedback on student comprehension can be obtained through individual activities such as reading quizzes *[28, 33]* or through whole-class activities such as multiple-choice questions with some type of response system (e.g., flashcards, finger signals).*[23, 28, 33]* Other individual activities include short writing exercises, partial outlines, critical thinking questions, reading reflection, affective response, one-minute papers, brainstorming, lists, matrices, and concept mapping.*[16, 21, 27, 33, 35, 36]* These activities also make good starting points for small-group or whole-class discussions. Techniques intended for pairs or small groups include "think, pair, share," debriefing, and thinking-aloud pair problem solving (TAPPS).*[21, 26, 27, 35]* Finally, student responses to the class session can be solicited using "Plus/Delta charts," "muddiest-point" submissions, and of course formal student assessments of instructional strategies.*[21, 26, 28, 33]*

Class activities are alternatives to lectures. They can substitute for a lecture or accompany a shorter, "mini" lecture. Class activities discussed in the literature include discussions, group work, interactive multimedia, and other exercises. Discussions can focus on readings, case studies, individual assignments or group projects.*[16, 33, 35, 36, 37]* Small groups or individuals can use tools such as interactive computer programs or multimedia workstations,*[25, 36]* do in-class "writing across disciplines,"*[16]* or work on assignments with supervision.*[34]* Students can work on entire problems in groups or do "jigsaw" group projects in which new groups are formed partway through the exercise to become expert in specific topics, then reassemble with their original groups to continue the exercise.*[33, 36]* Activities in some disciplines may include debates, drama, role-playing, simulation, and games.*[16, 33]* Other disciplines are more conducive to pre-lab or hands-on activities, or to modeling of skills by the instructor.*[24, 29, 38]* All disciplines can benefit from active review sessions or practice tests before exams.*[29, 33]* Two other techniques that are described in the literature are "just-in-time" teaching, which involves instructors responding to student questions or topics, and the Osterman feedback lecture, which is a structured series of mini-lectures with an accompanying study guide for self-directed learning.*[27, 34]*

Student-centered classes turn the focus away from the instructor to the student. The instructor's role in the entire course becomes that of an observer or facilitator. Types of student-centered classes discussed in the literature include cooperative learning,*[16, 33, 35, 36]* guided design,*[16]* mini-problem-based learning,*[21]* team learning,*[27]* peer teaching,*[16]* and an engineering design studio format.*[22]*

Each of these categories contains some activities that are appropriate in engineering courses. The "hard" nature of these courses, discussed in Section 2.1.4, renders activities focusing on opinions or emotions, such as debates and affective response, less useful. Many of the activities are well-suited to the "applied" nature of engineering, since they focus on using the course material rather than simply memorizing it. The choice of techniques for a particular course depends on the material that is to be learned as well as any constraints on resources such as time and money.

2.3. Structuring Active Learning

2.3.1 Course Structure

While lecture-based courses are intrinsically highly structured and controlled by the instructor, the structure of a course using active learning techniques requires more planning. Courses intended for first-year students or introducing students to a discipline need more structure than advanced courses, since both the content and the format are unfamiliar. "Such structure may take the form of more lecture time, more quizzes and other forms of interim feedback, more explicit and fewer open-ended tasks, and more face-to-face support from course staff when doing long-term out-of-class projects."*[15]*

Determining the activities to be completed inside and outside of class is one important aspect of designing course structure. Walvoord identified three components of learning: "first exposure," "process," and "response."*[39]* First exposure activities introduce students to course material, in the form of "new information, concepts, or procedures;" process activities are those in which students analyze, synthesize, and apply this material.*[39]* Response activities are those in which the teacher or other students "respond to the student's attempts at synthesis, analysis, problem-solving, or application."*[39]* Active learning methods would be considered process activities. Traditionally, classroom time has been used for first exposure activities, primarily lecturing, and process and response activities have taken place outside the classroom. The result is a need for out-of-class support by the instructor or teaching assistant, since students often need "explicit coaching" in problem-solving and application.*[15]* In other words, they need to approach the problem or use the skill with knowledgeable guidance.

In classes of more than thirty students, it can be difficult for the instructor to provide adequate support for activities outside the classroom. In these cases, more of the process activities should be done during class time.*[15]* Walvoord and Pool suggest that teaching can be more cost-effective if first exposure activities are largely completed outside of the classroom and classroom time is used for process and response activities.*[39]* If the class time is filled with process activities, there may be little time available for the instructor to cover basic course content, so the responsibility for reading and understanding the textbook and other resources (i.e., first exposure) falls heavily on the student. While this might be acceptable in some courses, such as literature, where the emphasis is on analysis and discussion of the reading, engineering students often need more guidance in and explanation of important concepts and procedures than is offered by a textbook. Computer software and other resources may be useful in this regard. Most importantly, some combination of in-class and out-of-class activities that is acceptable to the instructor and students should be sought.

Since most undergraduate students are less comfortable and familiar with active learning techniques than with traditional lectures, it is important to communicate the course format and expectations to them at the beginning of the course and to consistently reinforce them. The course syllabus can be used to explain the course format, discuss the responsibilities of students and instructor, and identify what is expected of students.*[40]*

2.3.2 Guidelines for Active Learning Exercises

"Nothing is gained by simply having students talk, listen, write, read, or reflect – unless those activities are well structured and guided by teachers."*[40]* To be effective, guidelines must be established for the active learning exercise to structure it appropriately.

Active learning methods that utilize small groups are often well-suited for problem-solving and discussion. Simply putting students in groups, however, does not help them learn. "How well small groups operate depends on the clarity of their objectives, the parameters of the activity, and the guidelines agreed upon for interaction."*[40]* Students need to understand why they are doing the activity, what they are supposed to do, and how they should behave as a group. Behavior guidelines can vary from simple discussion rules to detailed assigned roles. For informal activities, guidelines can include general points, e.g., one student should talk at a time, and the others should listen. For larger groups or longer exercises, specific roles can be identified and assigned to each member of the group.*[40]* Cooperative learning groups, for example, may include a leader, a recorder, and an encourager. The responsibilities of each role should be carefully spelled out.*[17]* In this way, the cooperation among students is more structured and more likely to be effective.

Discussion guidelines are discussed by Meyers in the context of different strategies: informal small groups, cooperative student projects, simulations, and case studies.*[40]* The Institute for Learning at the University of Pittsburgh also addresses this issue with the concept of "accountable talk." Accountable talk is discussion that promotes learning. Although developed for K-12 teaching, it has application to undergraduates as well. This concept says that discussion should be held accountable "to the learning community, to accurate and appropriate knowledge, and to rigorous thinking." Participants should listen to each other and respond to and further develop what others say; their contributions should be accurate and supportable; and they should use sound reasoning.*[41]* Such expectations should be clearly communicated to the students, through the syllabus or in the exercises themselves.

2.4. Learning Outcomes

Assessment of student learning in higher-education programs in the engineering fields, as well as in applied science, computing, and technology, is guided by the accreditation requirements of the Accreditation Board of Engineering & Technology (ABET). ABET's 2004-05 criterion 3 for engineering programs specifies that graduates must demonstrate:

a. an ability to apply knowledge of mathematics, science, and engineering;
b. an ability to design and conduct experiments, as well as to analyze and interpret data;
c. an ability to design a system, component, or process to meet desired needs;

d. an ability to function on multi-disciplinary teams;
e. an ability to identify, formulate, and solve engineering problems;
f. an understanding of professional and ethical responsibility;
g. an ability to communicate effectively;
h. the broad education necessary to understand the impact of engineering solutions in a global and societal context;
i. a recognition of the need for, and an ability to engage in life-long learning;
j. a knowledge of contemporary issues; and
k. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.*[1]*

Individual ABET-accredited engineering programs expand on these general outcomes in discipline-specific, measurable "program outcomes." For example, WPI's Department of Civil and Environmental Engineering has developed a set of eleven program outcomes by which it assesses student learning within the civil engineering program:

1. Preparation for civil engineering practice, including the technical, professional, and ethical components.
2. Preparation for the future changes in civil engineering.
3. A solid understanding of basic principles of civil engineering (i.e., computers / information technology, geographic positioning & measurements, solid / structural mechanics, soil mechanics, fluid mechanics / hydrology, design & problem-solving, construction materials, systems analysis & modeling, engineering economics & risk management).
4. An understanding of appropriate scientific concepts, and an ability to apply them to civil engineering.
5. An understanding of the engineering design process and an ability to perform engineering design, which includes the multidisciplinary aspects of the design process, the need for collaboration and communication skills, and the importance of cost and time management.

6. An ability to set up experiments, gather and analyze data, and apply the data to practical engineering problems.
7. In-depth understanding of at least one specialty within civil engineering.
8. Understanding of options for careers and further education, and the educational preparation necessary to pursue those options.
9. An ability to learn independently.
10. The broad education envisioned by the WPI Plan, and described by the Goal and Mission of WPI.
11. An understanding of the civil engineering profession in a societal and global context.*[42]*

Transportation engineering is considered a "specialty" or concentration within civil engineering. During the 2003-04 and 2004-05 academic years, courses in this area included CE3050 Introduction to Transportation Engineering; CE3051 Introduction to Pavement Materials, Design and Management; CE3054 Asphalt Technology; and CE405X Highway Design. Learning objectives are developed for each course and mapped to appropriate departmental measured outcomes. For example, for CE3050, the learning objectives relate primarily to technical components of civil engineering practice; basic principles of civil engineering (computers, problem-solving, and systems analysis & modeling); an ability to gather, analyze, and apply data; in-depth understanding of a civil engineering specialty (transportation engineering); and options for careers and further education. The learning objectives identified for CE405X relate primarily to basic principles of civil engineering (geographic positioning, design and problem-solving); understanding of the design process and ability to perform design; in-depth understanding of a civil engineering specialty (transportation engineering); and understanding of the profession in a societal context.

2.5. Summary & Hypothesis

Current learning theory represents learning as an active process in which students must do something with information in order to understand it. Students who encounter different ways of interacting with the material, such as the steps in the Kolb learning cycle, learn it more thoroughly. The idea of using active learning methods, now widely accepted, grew out of these theories. In past studies, active learning methods have seemed to result in greater understanding and more positive student responses to course material, in comparison to traditional lectures. Most of these studies focused on courses in the sciences and social sciences, and disciplinary differences may affect the objectives and applicability of some methods.

While the uses and apparent success of active learning in other disciplines have been discussed in many studies, the assessment of the effects of the techniques used has often been incomplete or missing entirely. One way to assess the effectiveness of different teaching methods is to evaluate how well the students demonstrate their mastery of the course learning objectives.

The hypothesis of this research is that the use of in-class, active-learning methods is significantly more effective in student achievement of some or all learning objectives in a transportation engineering course than the traditional lecture and out-of-class group activities. Assessment of the effectiveness of different teaching approaches, i.e., active-learning methods and lecture methods, is a crucial part of the research presented in this dissertation, and represents its primary contribution.

III. Experimental Approach

3.1. Scope

The literature reviewed in Chapter II indicates that active-learning methods are likely to be effective in transportation engineering classes, but that prior studies have not resulted in much quantitative assessment data. The objectives of this research were (1) to develop experimental active-learning-based undergraduate curricula for highway design and introductory traffic engineering courses, and (2) to assess the effectiveness of the experimental traffic engineering curriculum through an educational experiment. The project included the implementation of the experimental curricula and the collection and analysis of student performance and attitude data from control and experimental classes. A new course, CE405X Highway Design, was developed as a pilot study to test selected active-learning techniques.

The primary research focus was CE3050 Introduction to Transportation Engineering. Since the typical class size for CE3050 is 15 to 30 students, it was not feasible to divide students enrolled in one offering of the course into control and experimental groups. As a result, the experimental design used was quasi-experimental, meaning it did not involve random assignment of students to groups. The nonequivalent control group design was chosen, in which two treatment groups are pre-tested, administered a treatment, and post-tested. The two groups were students enrolled in two separate offerings of CE3050, and the two treatments were the control curriculum and the experimental curriculum.

One variation from a conventional nonequivalent control group design was that rather than administering the treatments to the two groups simultaneously, they were treated consecutively, in two course offerings one year apart. To avoid influencing student enrollment in the second group by changing the course format in the first iteration, the experimental treatment was administered to the second group of students.

3.2. Participants

The subjects of this study were all undergraduate students enrolled in CE3050 during the 2003-04 and 2004-05 academic years and all undergraduate students enrolled in CE405X during the 2003-04 academic year. The study included the initial offering of CE405X and two offerings of CE3050, for a total of 84 participants in three groups (each class was a group). The groups were self-formed by students' enrollment in the courses.

3.3. Procedures

The primary objective of this research was to implement an experimental curriculum for CE3050 and compare the resulting data to the data acquired in the control class of CE3050. The control and experimental classes of CE3050 are described in more detail in Chapter V.

All students in each CE3050 class completed a pre-test at the beginning of the term to assess their initial knowledge of the subject matter and initial attitudes toward transportation engineering. Both classes were guided by the same objectives, taught by the same instructor, and used the same textbook. During the first offering of CE3050, in fall 2003, I taught the class using the traditional lecture method with out-of-class reading and homework assignments and traffic study "laboratory" activities. This is referred to in this document as the "control class." During the second offering, I used an active-learning-based method along with lectures and out-of-class activities. This is referred to in this document as the "experimental class." The students in both classes took an exam covering half of the learning objectives at mid-term, and on the other half of the learning objectives at the end of the term. Near the end of the term, they also completed the IDEA student ratings of instruction form and an attitudinal survey.

While developing the experimental CE3050 curriculum, I also developed and taught a new undergraduate course in highway design, CE405X, using some of the active learning techniques suggested by the literature review. That course is referred to in this document as the "pilot course." I used student feedback and data from CE405X in developing the experimental CE3050 curriculum. Students in CE405X took a series of quizzes based on the learning objectives, worked on a group design project, and completed attitudinal pre- and post-surveys. The course is discussed in more detail in Chapter IV.

3.4. Instruments

There are no standard instruments for measuring transportation engineering knowledge or attitudes. I developed instruments for use in this study with the assistance of WPI's Center for Educational Development, Technology and Assessment (CEDTA). Appendix A contains copies of the instruments used in CE405X, and Appendix B contains copies of the instruments used in CE3050.

For both the control and experimental classes of CE3050, achievement of the course learning objectives was assessed by a pre-test and two exams administered during the course. Each exam addressed six of the twelve course learning objectives, which are enumerated in Chapter IV. Student attitudes toward the course and toward transportation engineering were assessed by pre- and post-surveys, supplemented by the IDEA student ratings of instruction short form with ten additional questions.

For CE405X, achievement of the course learning objectives (enumerated in Chapter IV) was assessed by a series of five quizzes and a group design project report. Student attitudes were assessed by a pre-survey and an end-of-course teaching methods survey, supplemented by the IDEA short form with no additional questions.

On the IDEA short form, students rate their progress on each of twelve general objectives using a five-point scale on which 1 is "low" and 5 is "high." The instructor designates a subset of these objectives as "essential" or "important" for reporting purposes. The student also responds to questions about his or her background, effort in the course, desire to take the course, attitude toward the field of study, quality of the instructor, and quality of the course. The IDEA Center reports both raw scores and adjusted scores; the adjusted scores take into account student work habits, desire to "take the course regardless of who taught it," and class size.

IV. CE405X Highway Design: Pilot Course

4.1. Curriculum Development

I designed CE405X as a new course in transportation engineering in which students learn the basics of highway design. Although WPI's civil engineering courses do not have prerequisites, the suggested background is a surveying course and CE3050. The course syllabus that I developed is included in Appendix A.

4.1.1 Selection of Content

The first step was to develop learning objectives based on the desired course topics, which were to include the highway design process, horizontal and vertical alignment, and cross-section elements. The objectives selected were that the students would be able to:

- Choose or determine appropriate design controls (design vehicle, speed, volume, etc.).
- Design a roadway cross-section.
- Estimate earthwork volumes.
- Calculate required sight distances for road segments and intersections.
- Design a vertical curve.
- Design a horizontal curve.
- Design a bicycle lane, sidewalk, and/or crosswalk.

For textbooks, I chose an American Association of State Highway and Transportation Officials (AASHTO) publication, *A Policy on Geometric Design of Highways and Streets*, and a Federal Highway Administration (FHWA) publication, *Flexibility in Highway Design*. The AASHTO book is the primary source of U.S. highway design guidelines, and the FHWA publication encourages design engineers to understand and utilize the flexibility inherent in those guidelines.

4.1.2 Teaching Methods

I used the learning objectives and the content of the textbooks to define the basic outline of the course. The next task was to select appropriate teaching methods that fit the objectives of the course and would provide useful feedback for the experimental CE3050 curriculum. The literature review provided an extensive list of active-learning methods, summarized in Section 2.2.3 of this report, which I narrowed down using several criteria.

The criteria for selecting teaching methods were based on my teaching philosophy and the practical constraints of the academic environment. My teaching approach shares the responsibility of learning between the instructor and the students; I focus on helping students learn where to find information, how to approach engineering problems, and how to design solutions. Criteria developed from this philosophy were that teaching methods must be appropriate for the content and discipline of the course, provide opportunities for active participation by all students, and share active roles and responsibility between the instructor and the students. The academic environment is characterized by a desire to cover much course material in a short period of time at no unnecessary expense. At WPI, undergraduate courses are completed in seven-week terms, usually in 50-minute class sessions about four times a week, and students take three courses per term. Criteria based on these factors were that teaching methods must show potential for effectiveness, require a reasonable workload for both the students and the instructor, and require little or no capital cost. In summary, the selection criteria chosen were:

- appropriateness (i.e., for content, discipline, and audience),
- accessibility (i.e., opportunity for active participation by all students),
- potential for effectiveness (based on research literature),
- time efficiency (i.e., reasonable workload for students and instructor),
- shared responsibility (i.e., active roles and responsibility shared between instructor and students), and
- low capital cost.

Appropriateness

The selected techniques were to be appropriate for both CE405X and CE3050, since CE405X was serving as a pilot course to evaluate techniques for use in CE3050. Both are undergraduate courses within civil engineering and emphasize facts, skills, and application of knowledge. As described elsewhere in this document, both courses are aimed primarily at juniors and seniors majoring in civil engineering, but there are no prerequisite courses. CE3050 focuses on traffic engineering, and CE405X focuses on the design of roadways.

Active interludes would be appropriate in both of these courses. These could include pauses, reflective pauses, or note comparison; multiple-choice questions or concept tests (with flashcards); brief interactive demonstrations or work at the blackboard; reading quizzes; and short individual or group exercises. The exercises could include "think, pair, share," brainstorming, visual lists, sample problems, thinking-aloud pair problem solving (TAPPS), matrix, critical thinking questions, or one-minute papers. Some other activities mentioned in the literature, such as short writing exercises, partial outlines, reading reflection, affective response, and concept mapping could be appropriate in some sessions but probably not useful on a regular basis.

Class activities that may be appropriate include discussion of assignments or group projects, supervised individual or group work, interactive computer programs or multimedia workstations, modeling of skills by the instructor, active review sessions, and the Osterman feedback lecture. Activities such as debates, drama, and role-playing have little application within the course topics, and most topics are not conducive to hands-on activities.

All the student-centered methods discussed in the literature could be appropriate. These include mini-problem-based learning, guided design, cooperative learning, peer teaching, team learning, and an engineering design studio.

Accessibility

All the methods mentioned above can be made accessible to all students. For example, while class discussion can be dominated by a few vocal students, the instructor can involve other students by techniques such as calling on students at random or grading participation.

Potential for effectiveness

All the methods mentioned have potential for effectiveness, based on the literature review. Some methods have been tested more thoroughly than others, but they all appear to have some promise. The class activities and student-centered methods require careful planning and facilitation to ensure that the class time is used effectively. Bringing these types of activities into class rather than assuming they will occur outside of class will allow instructor observation and guidance. "Ground rules" such as the guidelines for accountable talk would be critical in these types of activities.

Time efficiency

All the techniques would require some out-of-class reading or work by the students, based on the quantity and content of the material to be learned. Active interludes require the least student time outside of class, and student-centered methods probably require the most time.

The instructor workload is much more sensitive to teaching format than the student workload. No or little additional instructor time is needed to incorporate pauses, note comparison, or work at the blackboard into lectures, or to facilitate discussion of group projects and assignments or supervised individual or group work. Some additional instructor time is required to prepare multiple-choice questions, reading quizzes, concept tests, brief interactive demonstrations, or short exercises. Pre-packaged interactive computer programs, modeling of skills, and active review sessions are class activities that require some additional instructor time as well. The instructor time requirements of student-centered methods can be quite different from lecture-based classes, with much time consumed in course planning and less in teaching. Developing study guides for Osterman feedback lectures, new computer software, or multimedia presentations would add greatly to an instructor's workload, especially for the initial course offering, and thus these methods were removed from consideration.

Shared active roles and responsibility

This criterion means that the instructor and the students should both have active, meaningful roles in the class, and the responsibility for student learning should be shared between them. Several methods were discarded from consideration because they did not meet this criterion. Pauses alone do not involve the students actively, and interactive demonstrations and student work at the blackboard usually involve only a few students. On the other hand, supervised work and all the student-centered methods are heavily weighted toward student activity and responsibility. The remaining methods strike more of a balance between student and instructor activity and responsibility.

Little or no capital cost

None of the methods add substantial capital costs except interactive computer software and multimedia workstations. These two methods were removed from consideration.

Refined list of possible techniques

From the selection criteria and process described above, several techniques were considered the most suitable for use in this research:

Active interlude methods:

- Note comparison
- Multiple-choice questions or concept tests (with flashcards)
- Short exercises/problems (think, pair, share or small group); could include brainstorming, visual lists, sample problems, TAPPS, matrix, critical thinking questions, one-minute paper

Class activity methods:

- Discussion of group projects / assignments
- Modeling of skills
- Active review sessions

I chose three of these methods for use in the pilot course: multiple-choice questions, short exercises/problems, and discussion of group projects and assignments. Several studies discussed in the literature review used similar methods, but none of those studies quantified the relative effectiveness of the methods.*[23, 27, 29]*

Multiple-choice questions were used at the beginning of class sessions to encourage completion of the reading assignments and to check comprehension of concepts. Example questions are included in Appendix A. I printed each question on a transparency and displayed it for the class. After allowing a few moments for thought, I asked for raised-hand or oral responses. The responses were discussed but not graded. Such questions were used in six class sessions, primarily in the first two weeks.

Most class sessions were lecture-based. Short exercises, primarily problem-solving, were used as "active interludes" within the lectures. Rather than watching me solve example problems, students attempted to solve problems individually and in small groups.

I also created a design project and broke it down into numerous small pieces on which student groups worked during class sessions. For example, after a mini-lecture on design controls, each group selected an appropriate design speed and vehicle for its roadway, and then the two groups compared and discussed their choices. Some assignments were completed in class, while others were assigned as homework and discussed during the following session. Guidelines for effective discussions, based largely on the principles of accountable talk (see Section 2.3.2), were given out to the students as part of the syllabus (included in Appendix A) and presented briefly during the first class.

By combining these teaching methods, the course included the four steps in the Kolb and 4MAT learning cycles, discussed in Section 2.1.2. The reading assignments and, to some extent, the lectures provided the students with opportunities for reflective observation. The lectures primarily served the purpose of conceptualization, since their focus was on highway design concepts. The active interludes allowed the students to actively experiment with the concepts by solving small problems. Finally, the design project work and discussion provided "real-life" experience with the application of the concepts.

4.1.3 Assessment

Student learning was assessed through a series of quizzes addressing the course learning objectives and a group design project report. Each quiz consisted of four multiple-choice questions and was intended to be completed in ten to twenty minutes. The quizzes were closed-book, with the necessary tables and equation sheets provided, similar to the format of the Fundamentals of Engineering exam.*[43]* The project reports presented and discussed the design project that the student groups had worked on during the course. The quizzes and project report guidelines and grading rubric are included in Appendix A. The students also received grades for attendance and participation.

4.2. Student Profile

Six students participated in this course, including four seniors and one junior from within the civil engineering department and one out-of-major junior. There were two students, one male and one female, with a concentration in transportation; one female with a concentration in environmental engineering; two males with a concentration in structural engineering; and one male management engineering major. Four of the six students had taken CE3050, one in term A02 (i.e., prior to this study) and three in term A03 (i.e., the control class). Three had taken one or two courses related to pavements; only one, the environmental engineering student, had taken a course in hydraulics. Five had taken a course in AutoCAD, and at least two had taken a course in urban planning.

The CEE classes of 2004 and 2005 consisted of 41 and 54 students, respectively. According to the class rankings as of March 2004, the highway design class included one student ranked in the top 25% of the class; one in the second 25%; two in the third 25%; and one in the last 25%. While WPI does not use grade point average (GPA) as a measure of student performance due to the students' ability to "NR" a course (i.e., have no record of a failing grade), a GPA equivalent can be calculated by considering an A to be worth four points, a B three points, and a C two points. The GPA equivalent for the students in CE405X ranged from 2.62 to 3.65 as of March 2004.

4.3. Performance Data

The students completed five quizzes during the course to assess their comprehension of the course material. Each quiz contained four multiple-choice questions, and Quiz 5 also had a bonus question worth an extra 25 percent. All students took Quizzes 1, 2, 3, and 5, and five students took Quiz 4. Individual scores on the quizzes, shown in Table 4-1, ranged from 50 to 100 percent, with mean class scores ranging from 83 percent on Quiz 5 to 92 percent on Quiz 2. The mean class score for Quiz 4 was the average of five individual scores rather than six.

Table 4-1. Pilot Class Performance on Quizzes.

Student	*Quiz Scores (%)*					
	1	*2*	*3*	*4*	*5*	*Mean*
1	75	100	100	75	75	85
2	75	50	75	N/A	75	69
3	100	100	100	75	100	95
4	75	100	75	100	50	80
5	100	100	100	100	125	105
6	100	100	75	100	75	90
Mean	88	92	88	90	83	87

The students submitted written reports in groups of three after completing their class design projects. Qualitatively, these reports demonstrated a reasonably good understanding of the course objectives. They were graded according to the rubric shown in Appendix A and received scores of 88 and 99 percent.

Student performance was also assessed by their participation in in-class activities and discussions. In the 28 classroom sessions, no student was absent more than twice; there was a total of nine absences, four of which were discussed with me prior to class. The students received participation scores of 90 to 100 percent, with a mean of 96 percent. When present, they all participated satisfactorily in the in-class activities. Participation in discussion varied; sometimes the students became so interested and involved in the discussion that it was necessary to intervene in order to move on to another topic, while at other times much prompting from me was required to have any discussion at all. Factors that appeared to discourage discussion included the time of day (3 PM), warmth of the classroom, amount of work in other courses and projects, and occasionally lack of preparatory reading.

4.4. Student Feedback & Lessons Learned

4.4.1 Student Surveys

The six students completed a short pre-survey, included in Appendix A, during the first class session. In addition to basic demographic information (i.e., name, major and concentration, and class year), the survey contained questions about course background and interest in working in transportation engineering. The demographic information and course background were discussed in the previous section. Four of the six indicated that they were interested in working in the field of transportation engineering; these included two concentrating in transportation, one in structural, and one in management engineering.

During the last class session, the six students completed another survey focusing on the teaching methods used in the course, also included in Appendix A. This survey contained questions about whether each method was helpful in understanding the course material and/or in assessing the student's understanding, and whether the student enjoyed the methods. Five or six students agreed that each of the following methods helped them understand the course material: textbooks, other reading assignments, lectures, multiple-choice questions in lectures, quizzes, discussion of quizzes, in-class activities, in-class discussion, and group project work outside of class. Five or six students also agreed that each of the following helped them assess their understanding of the course material: multiple-choice questions in lectures, quizzes, discussion of quizzes, in-class activities, in-class discussion, and group project work outside of class. Responses were mixed with regard to the most helpful methods in both cases. The students were also asked which of the teaching methods encouraged them to read the reading assignments before class. Five agreed that lectures, quizzes, in-class activities, and in-class discussion encouraged them to read; four indicated that group project work outside of class encouraged reading; and three indicated that multiple-choice questions in the lectures encouraged reading. Five students indicated that they "usually" read the assignment before class, and the other one chose both "sometimes" and "usually," apparently meaning something between the two choices.

Since there were only six students in the class, it may be useful to look at differences among the individual responses to the teaching methods. The students were asked which methods were most helpful to them in understanding the course material and assessing their understanding, as well as which methods most encouraged them to read the assignments. Table 4-2 summarizes their responses and shows some demographic information as well. Based on the student comments (not shown in the table), students #3 and #5 were particularly fond of the in-class activities. Both were male; one was a civil engineering major specializing in transportation and one was a management engineering major whose engineering concentration was civil/transportation.

Table 4-2. Student Responses to Teaching Methods in Highway Design.

ID	*Gender*	*Area of study*	*Class year*	*Understanding helped by*	*Assessing helped by*	*Reading encouraged by*
1	Male	Structural	Junior	Lectures	Quizzes	Quizzes
2	Female	Environmental	Senior	Project (in & out of class)	Project work	Lectures
3	Male	Management engineering	Junior	Lectures	Quizzes	Reading assignments
4	Male	Structural	Senior	Lectures	In-class activities	Quizzes
5	Male	Transportation	Senior	Project (in & out of class)	Project work	In-class discussion
6	Female	Transportation	Senior	Reading assignments	In-class discussion	Lectures

Students' teaching method preferences could possibly be related to their GPA equivalent or class ranking. The students who chose project activities as most helpful to understanding were ranked 6^{th} and 40^{th} in their class of 41 students, with GPA equivalents of 3.65 and 2.62. The students who chose lectures as most helpful to understanding were ranked at the middle of their classes and had GPA equivalents ranging from 2.64 to 2.95.

All six students agreed that the textbooks used were well-suited to the course and would be useful references after the course. Regarding classroom methods, none of the students agreed with the statement, "The instructor lectured too much." They all indicated that they enjoyed the discussions and liked working on project-related activities in class, and disagreed with the statement, "I think the in-class activities were a waste of class time." The suggestions for improvement included:

- More interactive work during class
- More actual examples of roads
- Site visit
- Guest speakers
- Bullet lists of methods and ideas for project
- Use of relevant software in class and maybe as homework
- Change class time to earlier in the day

The survey also asked, "How has your interest in working in highway design changed after taking this course?" Interestingly, all six students chose the response, "more interested now."

All six students completed the short form of the IDEA student rating of instruction. The IDEA report summarizing the results of the survey is included in Appendix A. Table 4-3 shows the raw and adjusted scores for the measures of effectiveness used, based on a five-point scale. I had designated one objective as essential, "developing specific skills, competencies, and points of view needed by professionals in the field most closely related to this course;" and two as important, "gaining factual knowledge" and "learning to apply course material." Students also rated highly their progress on three objectives that I had not designated as essential or important: "learning fundamental principles, generalizations, or theories;" "acquiring skills in working with others as a member of a team;" and "acquiring an interest in learning more by asking my own questions and seeking answers;" with raw scores of 4.8, 4.7, and 4.0 respectively. The objectives of "developing creative capacities" and "learning how to find and use resources for answering questions or solving problems" received raw scores of 3.5 and 3.7. All other objectives that I had not designated as relevant scored well below 3.5.

Table 4-3. IDEA Score Summary for Pilot Highway Design Class.

Measure of Effectiveness or Progress	*Raw Score*	*Adjusted Score*
Progress on essential objectives:		
Professional skills, viewpoints	4.5	4.1
Progress on important objectives:		
Factual knowledge	4.5	4.2
Apply course material	4.8	4.5
Improved student attitude	5.0	4.6
Overall excellence of teacher	4.7	4.4
Overall excellence of course	4.5	3.9

The "improved student attitude" measure was above the IDEA average for both raw and adjusted scores. This measure is based on the survey statement, "As a result of taking this course, I have more positive feelings toward this field of study," to which all six students responded, "definitely true." The score supports the positive results of the exit survey question, "How has your interest in working in highway design changed after taking this course?"

4.4.2 Reflections on Teaching Methods

Three active-learning-based teaching methods were tested in this highway design course: multiple-choice questions, short exercises/problems, and discussion of group projects and assignments. The multiple-choice questions were intended primarily to encourage and check completion of assigned reading. Since the content of the mini-lectures often presumed that the students had read the assigned pages in their textbooks or handouts, it was important to assess whether they had in fact done so. These types of questions were used fairly regularly in the first weeks of the course, but it soon became apparent that (1) the students were usually reading the assignments and thus found the questions very easy, and (2) on the occasions when one or more students had not read the assignment, they did not seem affected by whether they answered the questions correctly or not. I had expected that answering an easy multiple-choice question incorrectly in the presence of peers would be a negative stimulus that would encourage a student to read the next assignment, but this did not seem to be the case. Probably these six students were comfortable enough with one another that none were particularly embarrassed by having the others witness their mistakes. A lack of such embarrassment was also evident in the class discussions that followed each quiz. On the teaching methods survey, only three of the six students indicated that multiple-choice questions in the lectures encouraged reading, and none chose this method as the one that most encouraged them to read.

Short exercises were used in almost every class session. Although presented as small-group exercises, in most cases the students worked individually and then compared answers within the small groups. This method appeared to be quite effective. Actually solving a problem or choosing a design value in class often revealed complexities that neither the reading or the mini-lecture had fully discussed. On several occasions, I provided assistance or pointed out mistakes in students' work, and the students commented that they were glad to be helped at that time rather than receiving a graded homework assignment with many corrections. The student response to this method on the teaching methods survey was overwhelmingly positive. All six students indicated that the in-class activities helped them understand the course material (five "strongly agreed" and one "agreed"), and two students chose "project (in and out of class)" as the most helpful methods in this regard; all six also agreed that these activities helped them assess their understanding of the material (four "strongly agreed" and two "agreed"), and one student indicated that the in-class activities were the most helpful method in such self-assessment. All six agreed that they liked working on the project activities in class, with three "strongly agreeing," and all disagreed that it was a waste of class time, with four "strongly disagreeing." As discussed in Section 4.4.1, the two male students most interested in working in transportation (one in civil engineering and one in management engineering) were particularly pleased with the in-class activities.

Whole-class discussions were also used in almost every class session. After most small-group exercises, each group reported back to the class (i.e., the other group and me) and time was allowed for discussion. Although both groups were working on the same basic roadway design scenario, their routes and design choices differed, so in most cases there were two answers or choices to compare and discuss. Several class sessions near the end of the course were also set aside for discussions of a series of case studies found in one of the course textbooks. The discussion technique appeared to be effective in that it provided opportunities to see some of the unforeseen effects of previous design decisions and also to hear different perspectives. The student response to in-class discussions was not as enthusiastic as the response to in-class activities. On the teaching methods survey, all six students agreed that the in-class discussions helped them understand the course material, but only one "strongly agreed" and none found this method the most helpful; five students agreed that the discussions helped them assess their understanding of the material, with three "strongly agreeing," and one chose this method as the most helpful in that regard. All six agreed that they enjoyed the discussions, but only one "strongly agreed;" there were no comments about the discussions, either positive or negative.

Discussions also occurred after each quiz so that all the students would know and understand the correct answers to the quiz questions. Although they often became instructor explanations rather than true discussions, this method appeared to be effective; before moving on to a new topic, I waited for all the students to indicate that they understood the correct answer and, where appropriate, the solution method. In most cases that happened very quickly, sometimes simply by revealing the correct answer and allowing the students to rethink the problem, so there was not much discussion required. On the teaching method survey, five students agreed that this discussion of quizzes was helpful in understanding the course material (two "strongly agreed") and all six agreed that it was helpful in assessing their understanding (one "strongly agreed"), but none of them chose this method as the most helpful in either regard.

In summary, the in-class short exercises and discussions used in this course seemed to be effective and well-received by the students. Students tended to view the exercises as more helpful overall in understanding the course material and assessing their understanding, while discussions were helpful primarily in assessing understanding. The multiple-choice questions were not as useful as expected because they did not seem to have a major impact on whether the students prepared for class by completing their assigned reading; the lectures and quizzes were more likely to encourage the students to read.

V. CE3050 Introduction to Transportation Engineering: Control and Experimental Classes

One of the objectives of this research was to assess the effectiveness of an experimental active-learning-based traffic engineering curriculum through an educational experiment. The course used for this experiment was CE3050 Introduction to Transportation Engineering. I taught a control class using the existing curriculum in A-term (i.e., the first quarter) of 2003, and an experimental class using the active-learning-based curriculum one year later, in A-term of 2004.

5.1. Curriculum Development

5.1.1 Course Content

In order to assess the effectiveness of the teaching methods independently of the course content, the learning objectives and topics covered were kept the same for the control and experimental classes. The course syllabi for both classes, which are substantially the same, are included in Appendix B, including topic outlines and course learning objectives. Topics covered in the course included an overview of transportation modes, organizations and careers; characteristics affecting operations; transportation networks and planning; functional classification of roads; traffic flow, capacity, and level of service concepts; traffic engineering studies; sign and signal warrants; signal timing; and traffic safety. The learning objectives that the students were expected to accomplish were to be able to:

1. Identify organizations and careers involved in the design, construction and maintenance of transportation systems.
2. Explain how characteristics of people and vehicles affect transportation operations.
3. Determine the functional classification of a road.
4. Collect and analyze traffic data.
5. Apply the travel demand forecasting process to a basic planning scenario.
6. Use traffic flow models to illustrate the relationships among volume, speed and capacity.

7. Identify data needed to determine the level of service of a basic highway or freeway segment; describe or perform a level-of-service analysis.
8. Choose an appropriate control type for an intersection.
9. Develop a signal timing plan for a signalized intersection.
10. Determine the capacity of lane groups at a signalized intersection.
11. Identify data needed to determine the level of service of a signalized intersection; describe or perform a level-of-service analysis.
12. Use data to assess safety at an existing roadway segment or intersection.

The textbook used was Nicholas J. Garber and Lester A. Hoel's *Traffic and Highway Engineering*, Third Edition, 2002 (ISBN 0-534-38743-8).

5.1.2 Teaching Methods

Sessions for both the control and experimental classes were held from 3:00 to 3:50 PM, four days a week (Monday – Thursday), during the first seven-week term of the school year (September – October). Both met in Room 116 of Kaven Hall at WPI.

For the control class, sessions consisted entirely of lectures, with the exception of exams. In each class session, one or two learning objectives were addressed. These learning objectives, along with a brief outline of the lecture, were displayed at the beginning of the session. Lectures were primarily oral, with PowerPoint or transparency slides and a chalkboard used to emphasize or illustrate important points or work problems. Lectures followed a detailed outline that was available to students after class on myWPI (campus Blackboard software) along with any PowerPoint slides. Student interaction was in the form of responses to my prompting for questions or answers, as well as a few group-building exercises near the beginning of the course.

For the experimental class, based on the experience with and feedback from the pilot course discussed in Chapter IV, I decided to use a lecture-based format with active interludes (i.e., exercises) and discussions. There were some differences between the pilot and experimental classes that had to be considered. The experimental class was expected to be much larger than the pilot class (i.e., over 30 students rather than six), and due to limited equipment the lab groups would consist of four or five students, larger than the three-person project groups in CE405X. Also, although both courses included components of analysis and design, the topics in CE3050 were broader in scope and were not well-suited to a coherent design project that could be broken down into in-class exercises and discussion topics.

As a result of these differences, the format of the exercises and discussions was altered somewhat. Most of the exercises were short problems to be solved by individuals or pairs of students and then briefly discussed by the instructor. Other longer tasks were related to the lab exercises and completed by the lab groups. Since the class was expected to be larger, fewer opportunities for whole-class discussion were included, replaced by discussion in small groups (i.e., two to five students) followed by debriefing.

I developed a series of exercises and discussion topics for the experimental class to be incorporated into the lectures (included in Appendix B). For example, during the third lecture, the following discussion topic was given:

> *A city engineer plans to install a stop sign at a 4-way intersection. The speed limit on the approach is 40 mph, and the approach is on a +5% grade. What affects the minimum distance from which the driver must be able to see the stop sign in order to stop?*

After taking suggestions and discussing possible factors, I introduced the class to the standard equation for stopping sight distance and showed them how it was developed. Then, instead of showing them an example, I gave them an exercise:

> *Calculate the total stopping distance required for the previous example and compare your answer with a person beside you.*

An outline of the lecture topics is also included in Appendix B. These topics changed very little from the control class. Since the lecture time was somewhat less than in the control class, I expected the students to have completed their reading assignments prior to class. Rather than spending class time defining terms, I provided students with a handout of important terms and definitions at the beginning of most class sessions to help them recall the vocabulary used in the reading assignments. Thus, part of the "reflective observation" in the Kolb learning cycle was moved outside of the classroom, and "active experimentation" was added into the classroom in the form of the exercises and discussions. As in the control class, lectures were primarily oral, with PowerPoint or transparency slides and a chalkboard used to emphasize or illustrate important points or work problems, and they followed a detailed outline that was available to students after class on myWPI (campus Blackboard software) along with any PowerPoint slides. The exercises and discussions were placed inside the lectures as active interludes or, in some cases, occurred at the beginning or end of the class session.

5.1.3 Assessment

The assessment of student performance was the same for the control and experimental classes, to allow comparisons between them. Assessment tools consisted of a pre-test and two exams. The students also completed graded homework assignments and group laboratory activities.

The pre-test was in the form of a knowledge survey, a tool suggested by Nuhfer and Knipp for assessing "changes in specific content learning and intellectual development."*[44]* The students were given a set of fifteen sample final exam questions, compiled from previous exams and course content, and asked to rate how confident they were in their ability to answer the questions with their "present" (pre-course) knowledge. The possible answers for each pre-test question were A, B, and C. Based on their current knowledge, students were instructed to choose A if they were "confident that [they could] now answer the question sufficiently for graded test purposes;" B if they could "answer at least 50% of the question" or knew "precisely where [they] could quickly find the necessary information and could then completely answer the question;" and C if they were "not confident that [they] could adequately answer the question." For analysis purposes, responses A, B, and C were converted to numerical scores of 10, 5, and 0 respectively. Questions 1-5, 7-8, and 14-15 dealt with the first six learning objectives; the other questions dealt with the remaining six objectives. The pre-test is included in Appendix B.

Homework problems were assigned and due twice a week, on Tuesdays and Thursdays. Most homework assignments consisted of two to three problems from the textbook, although some were handouts that I created. Each assignment addressed one or more of the course's learning objectives. The homework assignments in the experimental class were the same as for the control class.

Two laboratory activities (traffic data collection and analysis) were also assigned for student groups to complete outside of class. These assignments are included in Appendix B. In the first activity, each student group conducted a 24-hour traffic volume count of a road segment, using an automatic data recorder (Jamar's Trax I or NuMetrics' Hi-Star NC-97), and a two-hour turning-movement and pedestrian volume count of an intersection. The groups then produced reports and graphs of the data using appropriate software. In the second activity, the student groups used the data collected in the first laboratory to complete a preliminary study of the signalization of an intersection, including performing a signal warrant analysis, developing a preliminary signal timing plan, and performing a level-of-service analysis based on the timing plan. The students in the control class completed all laboratory work outside of the classroom; for the experimental class, some of the data analysis tasks for the lab assignments were begun and discussed in the classroom. In both cases, the student groups submitted written reports.

The students took two exams, one at approximately the middle of the term and the other on the last day of the course. The exams were identical for the control and experimental classes. The two exams were problem sets, each intended to assess six of the twelve course learning objectives. Students were given approximately one hour to complete each exam in class, and they were allowed to use any reference materials, including textbooks and class notes. The exams are included in Appendix B.

5.2. Student Profile

Students enrolling in CE3050 are primarily juniors or seniors majoring in civil engineering (CE). The characteristics of students enrolled in the control and experimental classes are summarized in Table 5-1. The control class included 33 juniors and seniors and one sophomore majoring in CE; their concentrations within CE included construction project management, environmental engineering, structural engineering, and transportation engineering. The other three students were a management engineering junior, an actuarial math junior, and a mechanical / fire protection engineering senior. The students in the experimental class were all CE majors, including 33 juniors and seniors, two transfer students, and six sophomores; their concentrations within CE included construction project management, environmental engineering, structural engineering, and transportation engineering, with over half focusing on structural engineering.

The class rankings are also shown in Table 5-1 for the juniors and seniors majoring in CE. These rankings represent the students' performance compared to other students in the same class year within the WPI Department of Civil and Environmental Engineering. The ranking information was updated in March 2004 for the control class and November 2004 for the experimental class. The experimental class also included six CE sophomores, two ranked in the top quarter of their class, one in the second quarter, one in the third quarter, and two in the last quarter.

Table 5-1. Characteristics of Students in Control and Experimental Classes.

	Control Class (A2003)	*Experimental Class (A2004)*
Gender	27 male 10 female	34 male 7 female
Year of study	20 seniors 16 juniors 1 sophomore	15 seniors 18 juniors 6 sophomores
Major field of study & concentration	34 Civil Engineering - 8 project management - 4 environmental - 11 structural - 4 transportation - 6 undecided / other - 1 unknown 1 Management Engineering 1 Actuarial Math 1 Mechanical / Fire Protection Engineering	41 Civil Engineering - 6 project management - 5 environmental - 21 structural - 4 transportation - 5 undecided / other
Class rankings within department (CE juniors and seniors only)	8 in top 25% 11 in second 25% 6 in third 25% 6 in lowest 25%	8 in top 25% 8 in second 25% 6 in third 25% 11 in lowest 25%

The control and experimental classes contained fairly representative samples of the juniors and seniors majoring in CE at WPI during the study period, as shown in Table 5-2. This table compares the two classes to the CE classes of 2005 and 2006 in terms of gender, class year, and GPA equivalent.

Table 5-2. Characteristics of Civil Engineering Juniors and Seniors.

	CE Juniors and Seniors		*All Students in CE Classes of 2005 & 2006 (as of Nov 2004)*
	In Control Class (as of Mar 2004)	*In Experimental Class (as of Nov 2004)*	
Gender	73% male 27% female	83% male 17% female	77% male 23% female
Year of study	58% seniors 42% juniors	45% seniors 55% juniors	48% seniors 52% juniors
GPA Equivalent			
Mean	3.10	2.95	3.03
Range	2.48-3.92	2.13-4.00	2.13-4.00

5.3. Assessment Data

The students completed the pre-test during the first class session of the term. Thirty-three of the 37 students in the control class and all 41 students in the experimental class participated in the pre-testing; the others were absent or had not yet joined the class. For the control class, mean scores on the test items ranged from two percent on questions 9 and 13 to 47 percent on question 11, and student scores for the entire pre-test ranged from zero to 43 percent, with a mean of 21 percent and standard deviation of 12 percent. For the experimental class, mean scores on the test items ranged from one percent on questions 9 and 13 to 45 percent on question 1, and individual scores for the entire pre-test ranged from 3 to 77 percent, with a mean of 21 percent and standard deviation of 15 percent. The mean scores and standard deviation for each question, for the two objective sets, and for the entire test are shown in Table 5-3; detailed data are included in Appendix C as Tables C-1 and C-2.

Table 5-3. Summary of Responses to Pre-test Questions.

	Control Class		*Experimental Class*		*Difference in Means (%)*
	Mean (%)	*Std Dev (%)*	*Mean (%)*	*Std Dev (%)*	
Q1	44	24	45	31	+1
Q2	42	40	43	37	+1
Q3	32	35	20	31	-12
Q4	17	30	22	31	+5
Q5	17	30	17	28	0
Q6	14	29	21	28	+7
Q7	14	29	22	28	+8
Q8	41	34	41	33	0
Q9	2	9	1	9	-1
Q10	23	33	24	29	+1
Q11	47	39	38	30	-9
Q12	5	15	6	23	+1
Q13	2	9	1	9	+7
Q14	6	17	9	22	+3
Q15	8	18	11	26	+3
Pre-test Total	21%	12%	21%	15%	0%
Objective Set 1	24%	14%	25%	15%	+1%
Objective Set 2	15%	13%	15%	12%	0%

At about the middle of the seven-week term, the students took the first exam. The control class scores ranged from 59 to 97 percent, with a mean of 80 percent and standard deviation of 11 percent. The experimental class scores ranged from 69 to 100 percent, with a mean of 85 percent and standard deviation of 8.3 percent. Table 5-4 summarizes the scores for each test question; detailed data are included in Tables C-3 and C-4 in Appendix C.

During the last day of class, the students took the second exam. The control class scores ranged from 19 to 93 percent, with a mean of 70 percent and standard deviation of 17 percent. The experimental class scores ranged from 15 to 104 percent, with a mean of 65 percent and standard deviation of 17 percent. Table 5-5 summarizes the scores for each test question; detailed data are included in Tables C-5 and C-6 in Appendix C.

Table 5-4. Summary of Performance on Exam 1.

	Control Class		*Experimental Class*		*Difference in Means*
	Mean	*Std Dev*	*Mean*	*Std Dev*	
Q1	80%	14%	79%	18%	-1
Q2	89%	18%	91%	15%	+2
Q3	57%	27%	65%	29%	+8
Q4	78%	28%	91%	12%	+13
Q5	94%	23%	92%	26%	-2
Q6	95%	10%	97%	11%	+2
Q7	88%	20%	95%	22%	+7
Q8	77%	22%	74%	22%	-3
Total	80%	11%	85%	8%	+5

Table 5-5. Summary of Performance on Exam 2.

	Control Class		*Experimental Class*		*Difference in Means*
	Mean	*Std Dev*	*Mean*	*Std Dev*	
Q1	50%	40%	40%	42%	-10
Q2	48%	33%	28%	40%	-20
Q3	80%	16%	81%	25%	+1
Q4	88%	29%	92%	22%	+4
Q5	77%	26%	80%	22%	+3
Q6	66%	38%	42%	47%	-24
Q7	67%	30%	72%	35%	+5
Q8	88%	29%	89%	29%	+1
Total	70%	17%	65%	17%	-5

Each exam assessed student knowledge of six of the course learning objectives. The student exam scores for each objective are summarized in Table 5-6; detailed data are included in Tables C-7 and C-8 in Appendix C.

Table 5-6. Summary of Exam Performance by Objective.

Objective	*Control Class*		*Experimental Class*		*Difference in Means*
	Mean	*Std Dev*	*Mean*	*Std Dev*	
1	77%	22%	74%	22%	-3
2	95%	10%	97%	11%	+2
3	80%	15%	79%	18%	-1
4	89%	18%	91%	15%	+2
5	57%	27%	65%	29%	+8
6	82%	20%	92%	11%	+10
7	80%	16%	79%	26%	-1
8	48%	33%	25%	38%	-23
9	77%	26%	80%	25%	+3
10	77%	26%	66%	27%	-11
11	74%	24%	78%	28%	+4
12	50%	40%	41%	42%	-9

Student performance on homework and laboratory assignments was not included in the analyses. These activities were completed outside of class and were unsupervised. Not all the students completed every homework assignment, and the assignments were graded by a different teaching assistant for each class. I graded the laboratory assignments, but they were group assessments rather than measures of individual performance.

5.4. Attitudinal Data

Student attitudes toward the course and toward transportation engineering were assessed by a pre-survey and a post-survey, supplemented by the IDEA student rating of instruction form.

The pre-survey consisted of five multiple-choice questions and seven statements for which the students were to indicate whether they agreed or disagreed. It was completed by 34 of the 37 students in the control class and 40 of the 41 students in the experimental class as part of their first homework assignment, using the myWPI survey feature. Since surveys on myWPI are anonymous, the results were reported on an aggregate basis. Based on the data from the survey and other sources, the students in the control class who did not respond to the survey were one senior and two juniors majoring in civil engineering, and in the experimental class, one sophomore majoring in civil engineering. In the experimental class, three students who later dropped the course also took this survey, and due to the fact that the survey results could not be disaggregated, their responses had to be included in the analysis.

Part of the survey focused on expectations about the course. The responses to these questions are summarized in Table 5-7. The most common response to the question, “Which of the following affected your decision to take this course?” was “curiosity about transportation engineering,” which supports the department’s treatment of this course as a “breadth course,” one which students take to explore an area of civil engineering.

Table 5-7. Student Expectations Regarding CE3050.

Survey Item	*Control Class*	*Experimental Class*
Which of the following affected your decision to take this course? (Choose all that apply.)	79% (26): Curiosity about transportation engineering 38% (13): Interest in transportation engineering as a career option 29% (11): Course reputation for being fun/interesting 26% (9): Interesting course description in the course catalog 9% (3): Good instructor reputation 6% (2): Course reputation for being easy 6% (2): Good student course evaluation results	67% (29): Curiosity about transportation engineering 33% (14): Interest in transportation engineering as a career option 16% (7): Course reputation for being fun/interesting 16% (7): Interesting course description in the course catalog 16% (7): Good instructor reputation 9% (4): Course reputation for being easy 2% (1): Good student course evaluation results
I expect this course to be boring.	79% (27) disagreed 21% (7) neutral 0% (0) agreed	65% (28) disagreed 35% (15) neutral 0% (0) agreed
I expect this course to be challenging.	0% (0) disagreed 68% (23) neutral 32% (11) agreed	2% (1) disagreed 68% (61) neutral 29% (37) agreed
I expect the material covered in this course to be useful in my career.	3% (1) disagreed 15% (5) neutral 82% (28) agreed	0% (0) disagreed 23% (10) neutral 77% (33) agreed

Another part of the survey focused on attitudes about transportation and traffic engineering. The responses to these questions are summarized in Table 5-8. Interestingly, although only four of the responding students in each class indicated that they were specializing in transportation, thirteen and twelve in the control and experimental classes respectively indicated that they were interested in working in the field of transportation engineering.

Table 5-8. Initial Student Attitudes Toward Transportation Engineering.

Survey Item	*Control Class*	*Experimental Class*
Transportation engineering is a rewarding career.	0% (0) disagreed 56% (19) neutral 44% (15) agreed	0% (0) disagreed 65% (28) neutral 35% (15) agreed
Traffic engineers have an easy job.	38% (13) disagreed 47% (16) neutral 15% (5) agreed	33% (14) disagreed 65% (28) neutral 2% (1) agreed
Traffic engineering requires a significant amount of specialized knowledge.	3% (1) disagreed 26% (9) neutral 71% (24) agreed	2% (1) disagreed 28% (12) neutral 70% (30) agreed
I am interested in working in the field of transportation engineering.	12% (4) disagreed 50% (17) neutral 38% (13) agreed	28% (12) disagreed 44% (19) neutral 28% (12) agreed

One post-survey was a self-assessment of student achievement. In this it differed from the end-of-course survey for CE405X, which focused on teaching and learning methods in order to help the development of the experimental curriculum for CE3050. The students in CE3050 were given a table of the twelve course learning objectives and asked which objectives were particularly difficult to master, how well they thought they had achieved each objective, and how well their achievement was assessed by the homework, exams and/or lab exercises. The survey was not anonymous, but the students were assured that their responses would not affect their grades. All the students completed this post-survey, probably because submission of a completed survey earned them extra points on the final exam.

In the control class, over half the students identified objectives 7, 9, and 11 as "particularly difficult" (21, 19, and 25 students respectively). Objectives 7 and 11 were to “identify data needed to determine the level of service of a basic highway or freeway segment (7) and a signalized intersection (11) and describe or perform a level-of-service analysis;” objective 9 was to “develop a signal timing plan for a signalized intersection.” Not surprisingly, the class as a whole rated their achievement of these three objectives most poorly as well. In the experimental class, over half the students identified objectives 9, 10, and 11 as “particularly difficult” (29, 24, and 26 students respectively). These objectives were closely related: to “develop a signal timing plan for a signalized intersection” (9), “determine the capacity of lane groups at a signalized intersection” (10), and “identify data needed to determine the level of service of a signalized intersection and describe or perform a level-of-service analysis” (11). This class as a whole rated their achievement of these three objectives most poorly. The objectives rated by both classes as “particularly difficult” were relatively complex tasks, requiring a number of steps to solve a problem. The intersection-related objectives were also included in the second laboratory assignment, and the challenge of applying the concepts and procedures to a real-life problem may have magnified their difficulty in the eyes of the students.

In the control class, the students’ average rating of their own achievement ranged from 2.7 to 4 (on a numerical scale of 1 to 4, 4 being the highest score), and the average ratings for objectives 7, 9, and 11 were 2.8, 2.9, and 2.7 respectively. In the experimental class, the students’ average rating of their own achievement ranged from 2.6 to 4, and the average ratings for objectives 9, 10, and 11 were 2.7, 2.8, and 2.6 respectively. Interestingly, in both classes the students’ self-assessment of achievement of the objectives varied considerably from the apparent achievement based on homework, lab, and exam grades, as shown in Table 5-9. The students’ average rating of the quality of the assessment tools (i.e., labs and exams) for each objective ranged from 3.1 to 3.7 on the same scale in the control class, and from 2.8 to 3.5 in the experimental class; the overall average ratings were 3.4 and 3.2, respectively.

Table 5-9. End-of-Course Self-Assessment Versus Grading Assessment (based on exam scores converted to a five-point scale).

	Control Class		*Experimental Class*	
Objective	*Mean Student Self-Assessment*	*Mean Grade Assessment*	*Mean Student Self-Assessment*	*Mean Grade Assessment*
1	3.8	3.4	3.6	3.3
2	4.0	3.5	4.0	3.6
3	3.7	3.5	3.5	3.4
4	3.4	3.5	3.5	3.5
5	3.0	2.4	3.2	2.7
6	3.2	3.1	3.3	3.2
7	2.8	3.2	3.1	3.2
8	3.1	2.2	3.1	1.9
9	2.9	3.2	2.7	3.0
10	3.0	3.0	2.8	2.2
11	2.7	2.9	2.6	2.5
12	3.3	2.3	3.2	1.9
Overall	*3.2*	*3.0*	*3.2*	*2.9*

The short form of the IDEA student rating of instruction was completed by 35 of the 37 students in the control class and 24 of the 41 students in the experimental class. The IDEA report summarizing the results of the survey is included in Appendix B. Table 5-10 shows the raw scores for the measures of progress and effectiveness used, based on a five-point scale where 1 is "low" and 5 is "high." Students rated highly their progress on two objectives that I had not designated as essential or important: learning to apply course material and acquiring skills in working with others as a member of a team, with raw scores of 3.9 and 3.8 respectively in both classes. All other objectives that I had not designated as relevant were rated well below 3.5 by the control class. The experimental class did rate one other objective at 3.4: acquiring an interest in learning more by asking my own questions and seeking answers.

Table 5-10. IDEA Score Summaries for CE3050.

Measure of Progress/Effectiveness	*Raw Scores for Control Class*	*Raw Scores for Experimental Class*
Progress on essential objectives:		
Factual knowledge	4.0	4.1
Principles and theories	3.9	3.9
Progress on important objectives:		
Professional skills, viewpoints	3.9	4.0
Use of resources to answer questions	3.5	3.6
Improved student attitude	3.6	3.8
Overall excellence of teacher	3.4	3.9
Overall excellence of course	3.6	3.5

The ten "extra questions" that I developed for the IDEA form are included in Appendix B. Seven of the additional questions were agree/disagree statements similar to the ones on the pre-survey, two were questions about the learning activities used in the course, and one identified the student's area of concentration within civil engineering to help match the responses to the pre-surveys. Unfortunately, only 18 of the students in the experimental class responded to these extra questions, probably due to lack of time.

The students were first asked to choose one item from a list as the most helpful in learning the course material. In the control class, 47 percent of the respondents chose homework, 35 percent chose lecture notes and slides on MyWPI, fifteen percent chose lectures, and three percent chose lab exercises. In the experimental class, 67 percent chose homework, 22 percent chose lecture notes and slides on MyWPI, six percent chose lectures, and six percent chose lab exercises.

The students were also asked to agree or disagree, on a scale of 1 to 5, with eight statements. Seven of the statements were similar to those on the pre-survey, and the results are compared in Table 5-11. Responses of 1 or 2 ("strongly disagree" or "disagree") were grouped together as "no;" responses of 4 or 5 ("agree" or "strongly agree") were grouped as "yes;" responses of 3 were neutral and are not included in the table. Overall, the student responses in the control class indicated a less positive attitude toward transportation engineering in general and this course in particular after the course than before it. In the experimental class, the student responses indicated a less positive attitude toward the course but slightly more positive attitudes toward transportation engineering in general. The majority of the students in both classes indicated that they did not read the reading assignments on a regular basis.

Table 5-11. Student Expectations and Reactions (based on surveys).

Summary of Statement	*Pre-Survey*		*IDEA Form*	
	Control	*Experimental*	*Control*	*Experimental*
I expect this course to be boring. (This course was boring.)	0% yes 79% no	0% yes 65% no	49% yes 14% no	17% yes 44% no
The material covered in this course will be useful to me in my career.	82% yes 3% no	77% yes 0% no	20% yes 63% no	39% yes 28% no
I expect this course to be challenging. (This course was challenging.)	32% yes 0% no	29% yes 2% no	26% yes 31% no	33% yes 11% no
Transportation engineering is a rewarding career.	44% yes 0% no	35% yes 0% no	29% yes 23% no	44% yes 11% no
Traffic engineers have an easy job.	15% yes 38% no	2% yes 33% no	23% yes 23% no	6% yes 67% no
Traffic engineering requires significant specialized knowledge.	71% yes 3% no	70% yes 2% no	43% yes 14% no	78% yes 12% no
I am interested in working in the field of transportation engineering.	38% yes 12% no	28% yes 28% no	14% yes 37% no	17% yes 55% no
I read the reading assignments on a regular basis.	N/A	N/A	17% yes 60% no	12% yes 50% no

All the student comments written on the IDEA form are included in Appendix B. Most comments were suggestions for improvement in the course. Comments about teaching methods from the control class included:

- “While I liked the course and did find it challenging, I often found myself day-dreaming during class and never felt compelled to listen in lecture. I would suggest that lecture be more engaging and require the participation of students.”

- “I think that this course could have been more useful and fun had we seen more real world application examples.”

- "There could have been something to make the class more interesting. A field trip / videos would have been helpful."

- "Method of teaching was frustrating – I often felt like I was learning more from notes online and book despite going to class everyday. Labs and such could have been really fun (overall material is interesting, just presentation is so dry and full of calculations), but weren't. Prof seems excited and interested in topics, but couldn't really share her enthusiasm."

Comments about teaching methods from the experimental class included:

- teaching methods: "Good!"

- "Labs were helpful – need more!!"

- "Suggestion: more field work. Teaching methods: maybe class time could be more upbeat and interesting with people getting involved in discussion."

- "In class exercises not useful."

- "No improvements. I enjoyed the [teaching] methods she used."

VI. Analysis of Data from CE3050 Classes

6.1. Pre-test and Post-test Scores

The datasets from the control and experimental classes consist of: pre-test scores for objective sets 1 and 2; post-test scores for objective set 1 (mid-term exam) and objective set 2 (final exam); pre- and post-survey questions; and summary scores from the IDEA forms. Objective set 1 is comprised of the first six CE3050 course objectives, while objective set 2 is the remaining six objectives. Table 6-1 shows descriptive statistics for each pre-test and post-test: mean scores, standard deviations ("SD"), and skewness ("skew"). Skewness is a measure of the lack of symmetry in the score distribution; a negative skewness value indicates that the data is skewed to the right of the normal distribution.

Table 6-1. Descriptive Statistics for Pre-test and Post-test Scores.

Test	*Control Class*			*Experimental Class*		
	Mean	*SD*	*Skew*	*Mean*	*SD*	*Skew*
Pre-test: objective set 1	24.5	14.0	0.36	25.5	14.9	1.76
Pre-test: objective set 2	15.1	13.1	0.47	15.2	12.1	2.25
Post-test: objective set 1	80.5	10.5	-0.18	84.8	8.3	0.09
Post-test: objective set 2	70.9	16.4	-1.15	64.8	17.0	-0.55

6.1.1 Initial Knowledge

Figures 6-1 and 6-2 compare the control and experimental classes' pre-test scores for each objective set. Pretest scores of the two groups were compared using the t-test for independent samples (see Equation 1). A t-value of at least ±1.9960 would indicate a significant difference between the two groups at a 95 percent confidence level. For the pretest scores on the first set of objectives, $t = -0.2877$, and for the second set of objectives, $t = -0.0256$. These values indicate that there was not a significant difference between the two groups' average initial perception of their knowledge of course content.

Equation 1. T-test for independent samples.

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\left(\frac{SS_1 + SS_2}{df}\right)\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}, \text{ where } \begin{cases} SS_1 = \sum X_1^{\ 2} - \frac{\left(\sum X_1\right)^2}{n_1}, \\ SS_2 = \sum X_2^{\ 2} - \frac{\left(\sum X_2\right)^2}{n_2} \\ df = n_1 + n_2 - 2 \end{cases}$$

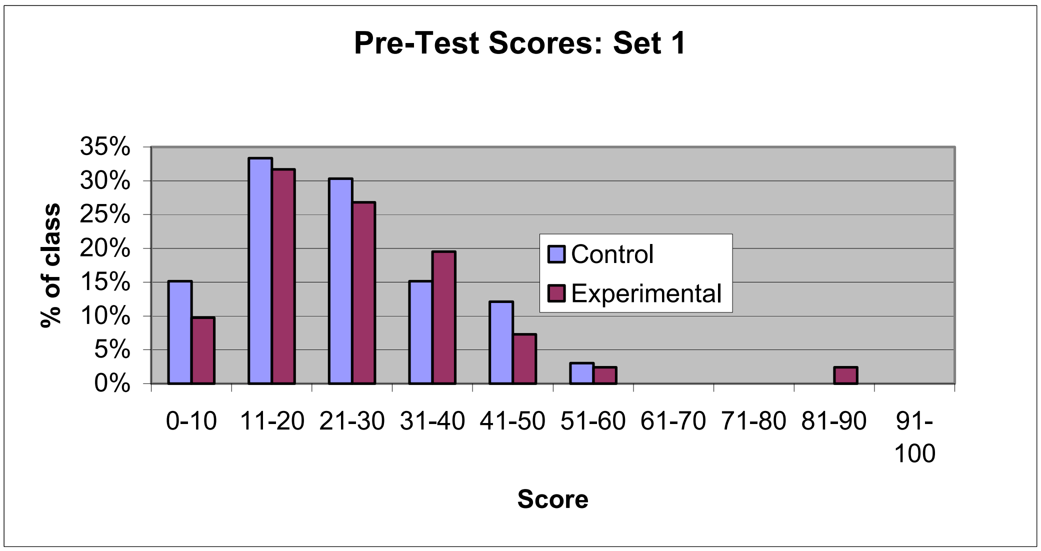

Figure 6-1. Pre-test Scores for Objective Set 1.

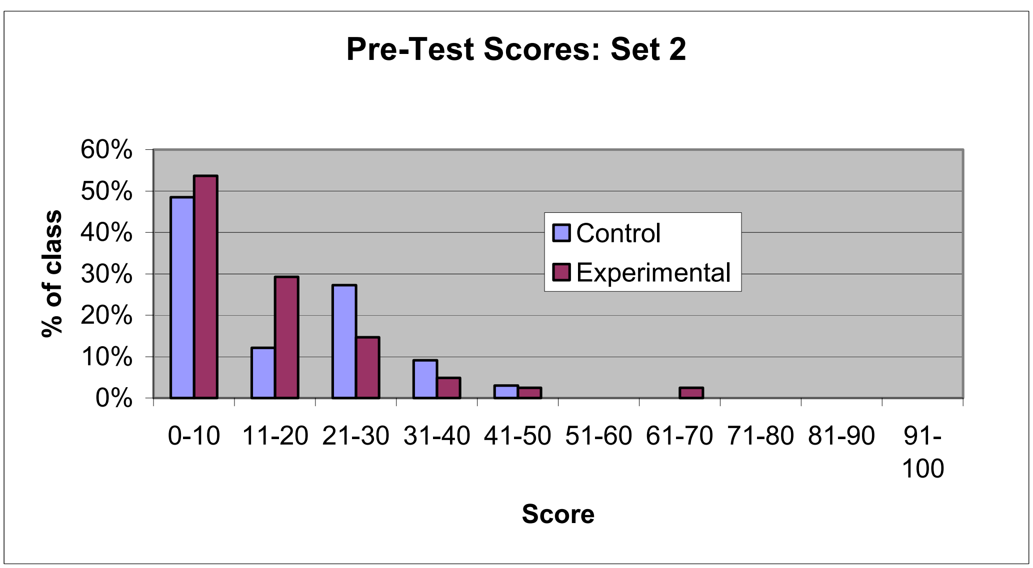

Figure 6-2. Pre-test Scores for Objective Set 2.

6.1.2 Change in Knowledge During Course

Scores from the mid-term exam, representing achievement of one set of learning objectives, were compared to the pre-test scores on objective set 1 using the t-test for non-independent samples (see Equation 2). The same test was used to assess changes in knowledge of the second set of objectives based on the end-of-term exam.

Equation 2. T-test for non-independent samples.

$$t = \frac{\overline{D}}{\sqrt{\dfrac{\sum D^2 - \left(\sum D\right)^2 / N}{N \times df}}}$$

, where D = difference between matched pairs,
N = number of pairs (15), and
df = N-1

For the control class, the dataset included 33 sets of scores, since four students did not take the pretest; thus a t-value of at least ±2.038 would indicate a significant difference between the pretest and posttest scores at 95 percent confidence. The actual t-values for objective sets 1 and 2 were 15.77 and 15.92, respectively. These values indicated a positive change that was significant at 99.9 percent confidence.

For the experimental class, the dataset included 41 sets of scores; thus a t-value of at least ±2.021 would indicate a significant difference at 95 percent confidence. The actual t-values for objective sets 1 and 2 were 20.19 and 19.33, respectively, which indicated a positive change significant at 99.9 percent confidence.

Clearly, both the control and experimental treatment (teaching methods) resulted in student learning.

6.1.3 Achievement of Learning Objectives

The main question in this study was whether the method of instruction affected the students' learning or attitudes. The post-test scores for each class are shown in Figures 6-3 and 6-4.

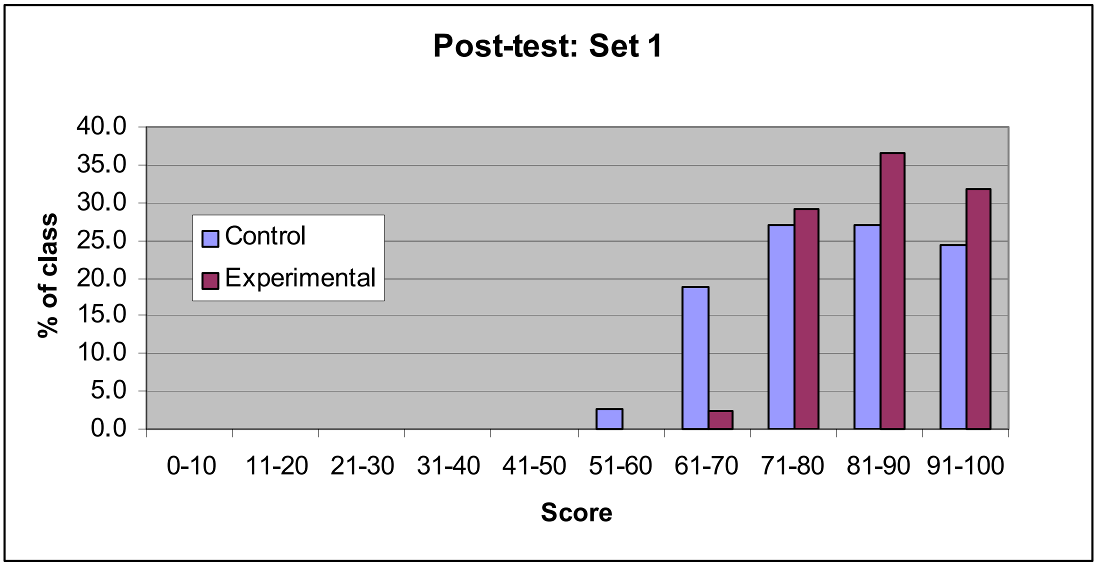

Figure 6-3. Post-test Scores on Objective Set 1.

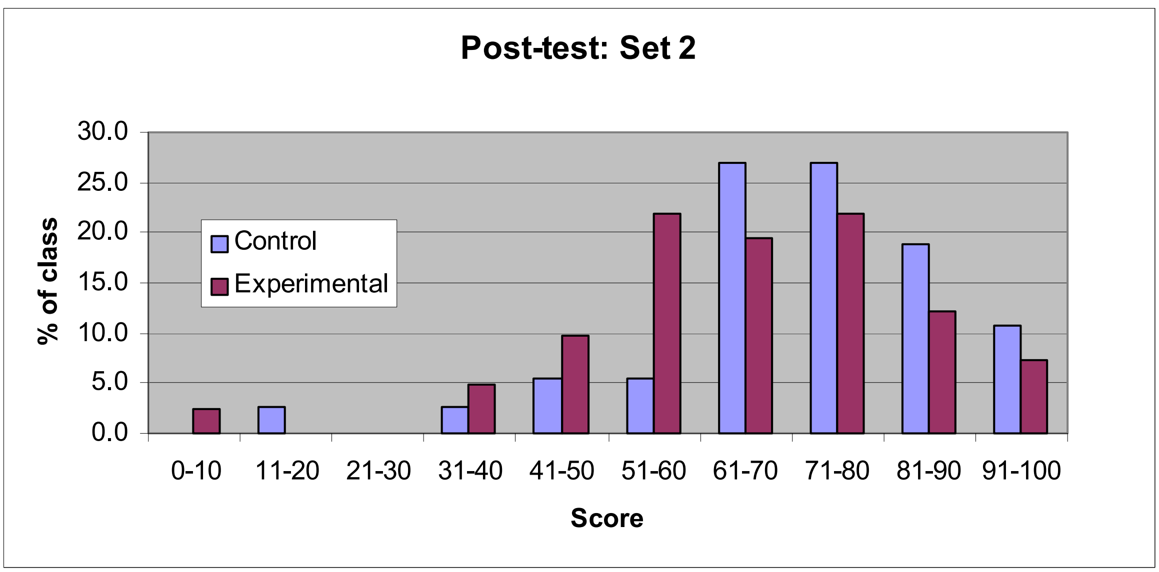

Figure 6-4. Post-test Scores on Objective Set 2.

The mean scores of each class on the post-tests were compared using the t-test for independent samples (Equation 1). A t-value of at least ±1.9947 would indicate a significant difference between the classes at a 95 percent confidence level. For the post-test covering the first set of objectives, the t-value was –1.9996; for the test on the second set of objectives, the t-value was –1.6113. These values reveal that overall the results were favorable. The experimental class performed significantly better than the control class on the first set of objectives, which means that the experimental treatment (teaching method) had a positive effect. The score distributions in Figure 6-3 illustrate this effect by a shift to the right from the control to the experimental classes. The fact that there was no significant difference between the groups on the second set of objectives means that the variation between them can be explained by chance rather than by effects of the treatments. The score distributions in Figure 6-4 show quite a bit of variation within each class.

Similar analyses were conducted to compare the post-test scores of several sub-groups. The scores of males and females taken separately showed no significant differences even at 90 percent confidence. The scores of CE juniors and seniors followed the same pattern as those of the entire classes; at 95 percent confidence, those in the experimental class performed significantly better on the post-test of objective set 1 and showed no significant difference in performance on the post-test of objective set 2. The CE juniors and seniors were also analyzed in two subgroups: students in the top half of their class and those in the bottom half. The differences between the mean scores for the students in the bottom half of their classes were not statistically significant even at 90 percent confidence, but of the students ranked in the top half of their classes, those in the experimental class did perform significantly better (at 95 percent confidence) on the post-test of objective set 1 than those in the control class.

Since the effects of the experimental treatment appeared to vary between the two sets of objectives, I examined the objectives more closely to identify differences. As in many courses, the objectives taught later in the course (i.e., set 2) tended to be more complex, building on what was taught earlier in the course (i.e., set 1). The differences in the effectiveness of the approach could possibly be explained by the level of complexity associated with the objectives; perhaps the exercises and discussions were more valuable in learning the less complex tasks of objective set 1. Another factor that I suspect may have been more important is the level of student participation in the in-class exercises and discussions. As the term progressed, the students seemed to be increasingly tired in general and less likely to be actively involved in class. I did not collect data on the level of participation, but I did notice that in the last half of the term, more students simply waited for me to show them how to do the exercise rather than doing it themselves; this would negate the purpose of the active learning exercise.

One other possibility is that the thinking processes involved in the objectives were a factor in the effects of the teaching approach. Table 6-2 summarizes the objectives and the thinking processes involved in them, based on the stated objective and the related exam questions. These thinking processes were discussed in the literature review. The table also shows the differences between the experimental and control classes in terms of mean scores on the exam questions related to each objective. Description was used for three objectives in set 1 and one objective in set 2; the score differences were minimal except for objective 11, where description was combined with selection and inference. Selection was used for two objectives in set 1 and four objectives in set 2; the score differences tended to be negative (i.e., the control class performed better) where selection was combined with inference and positive where it was combined with synthesis. Representation was used for two objectives in set 1 and none in set 2; in both cases the experimental class performed better. Inference was used for two objectives in set 1 and three in set 2; in all cases except where combined with representation, the control class performed better than the experimental class. Synthesis was used for one objective in set 1 and three in set 2; the differences were small. Verification was used only for one objective in set 2, combined with inference, and the control class performed better in that case. It seems that the experimental treatment had a positive effect for learning objectives involving representation or a combination of selection and synthesis, and a negative effect for objectives involving inference.

Table 6-2. Thinking Processes Used in CE3050 Learning Objectives.

Set	*Learning Objective*	*Thinking Processes*	*Difference in Mean Scores (Exp'l – Control)*
1	Identify organizations and careers involved in the design, construction and maintenance of transportation systems.	Description	-3
	Explain how characteristics of people and vehicles affect transportation operations.	Description Selection	+2
	Determine the functional class of a road.	Inference	-1
	Collect and analyze traffic data.	Description	+2
	Apply the travel demand forecasting process to a basic planning scenario.	Selection Representation Synthesis	+8
	Use traffic flow models to illustrate the relationships among volume, speed and capacity.	Representation Inference	+10
2	Identify data needed to determine the level of service (LOS) of a basic highway or freeway segment; describe or perform an LOS analysis.	Selection Synthesis	-1
	Choose an appropriate control type for an intersection.	Selection Inference	-23
	Develop a signal timing plan for a signalized intersection.	Synthesis	+3
	Determine the capacity of lane groups at a signalized intersection.	Description Selection Inference	-11
	Identify data needed to determine the LOS of a signalized intersection; describe or perform an LOS analysis.	Selection Synthesis	+4
	Use data to assess safety at an existing roadway segment or intersection.	Inference Verification	-9

6.2. Attitudinal Measures

The items on the pre-survey and the IDEA post-survey assessing attitude toward the course and toward transportation engineering (i.e., questions 6-12 on the pre-survey and 21-27 on the IDEA survey) were almost identical. Scores were assigned to each response based on a scale of five points for the most positive choice (i.e., "strongly agree" or "strongly disagree," depending on the question) down to one point for the most negative choice. Due to the nature of the surveys and survey processing (e.g., not all the survey answer sheets were returned by the IDEA Center), an aggregate score for each student was not available, so the data consisted of scores for each question separately. The attitude scores were divided into attitudes toward the course (three items) and toward transportation engineering as a career (four items).

Tables 6-3 and 6-4 show the mean scores, standard deviation, and skewness of the responses to each survey item. The IDEA survey data refer to the raw (unadjusted) scores.

Table 6-3. Descriptive Statistics for Pre-Survey Attitude Scores.

Focus	*Survey Item Summary*	*Control Class*			*Experimental Class*		
		Mean	*SD*	*Skew*	*Mean*	*SD*	*Skew*
Course	Course will be boring.	3.9	0.6	-0.02	3.8	0.7	0.28
	Course material will be useful.	4.0	0.7	-0.57	3.9	0.6	0.05
	Course will be challenging.	3.4	0.5	1.23	3.3	0.5	0.14
Career field	It is a rewarding career.	3.5	0.6	0.83	3.4	0.5	1.03
	It is an easy job.	3.7	0.8	0.13	3.4	0.6	0.94
	It requires specialized knowledge.	3.9	0.8	-0.22	3.7	0.7	-1.51
	I am interested in working in it.	3.4	1.0	0.02	3.0	1.0	-0.03

Table 6-4. Descriptive Statistics for IDEA Post-Survey Attitude Scores.

Focus	*Survey Item Summary*	*Control Class*			*Experimental Class*		
		Mean	*SD*	*Skew*	*Mean*	*SD*	*Skew*
Course	Course was boring.	3.0	1.0	-0.24	3.4	1.1	-0.29
	Course material will be useful.	3.0	1.2	-0.30	3.2	0.8	0.87
	Course was challenging.	3.0	0.8	-0.05	3.3	0.8	0.41
Career field	It is a rewarding career.	3.3	0.9	-0.42	3.4	0.9	0.19
	It is an easy job.	3.3	1.0	-0.36	3.7	0.8	-0.41
	It requires specialized knowledge.	3.7	1.0	-0.84	3.8	1.0	-1.47
	I am interested in working in it.	2.8	1.1	-0.17	2.5	1.3	0.52

6.2.1 *Initial Attitudes*

Figure 6-5 shows the mean scores for the pre-survey items. As for the pre-test, the attitude scores from the pre-survey were compared between classes using the t-test for independent samples (see Equation 1). With a total of 77 student responses, a t-value of at least ±1.995 would indicate a significant difference between the classes at a 95 percent confidence level; the actual values for the individual questions ranged from -0.527 to –0.005. These values indicate that there was no significant difference between the two classes in terms of their initial attitude toward the course and the career field. The mean scores varied between the classes by 0.4 or less on a scale of 1 to 5.

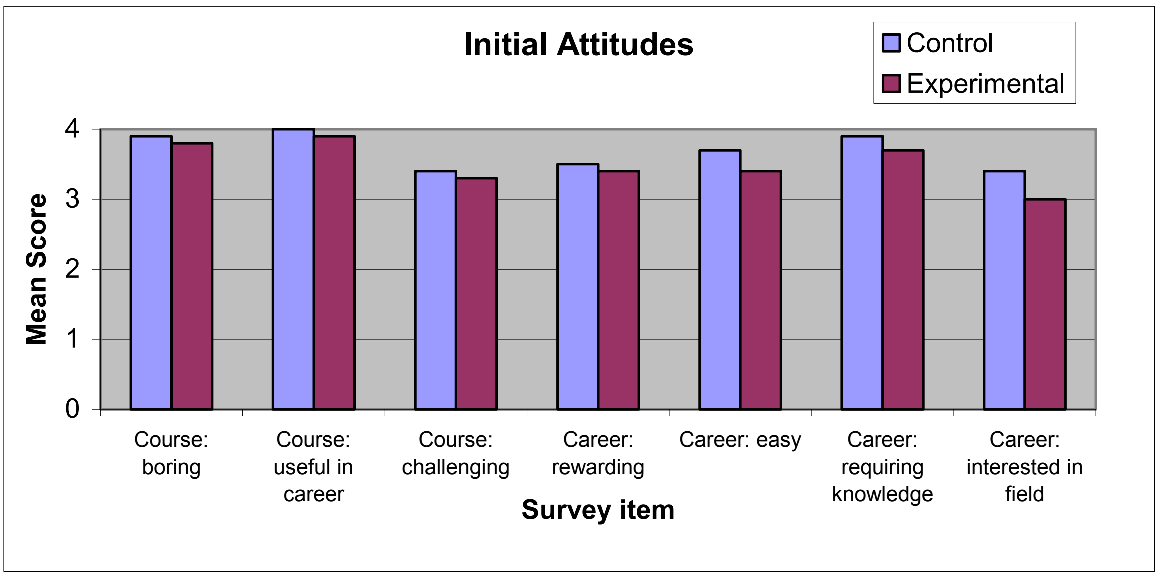

Figure 6-5. Initial Attitude Scores.

6.2.2 *Change in Attitudes During Course*

The change in attitudes from the pre-survey to the IDEA post-survey was assessed by the t-test for non-independent variables (see Equation 2). For the control class, with a total of 68 student responses on the two surveys, a t-value of at least ±1.998 would indicate a significant change at a 95 percent confidence level; the actual values for the individual questions ranged from –1.173 to –0.184. For the experimental class, with a total of 61 student responses on the two surveys, a t-value of at least ±2.001 would indicate a significant change at 95 percent confidence level; the actual values ranged from –0.672 to 0.349. These values indicate that the changes in students' attitudes toward the course and career field were not significant.

It is interesting to note, however, the trends in the attitude changes. Figures 6-6 and 6-7 show the attitude scores on the pre-survey and those on the IDEA post-survey for the control class and experimental class, respectively.

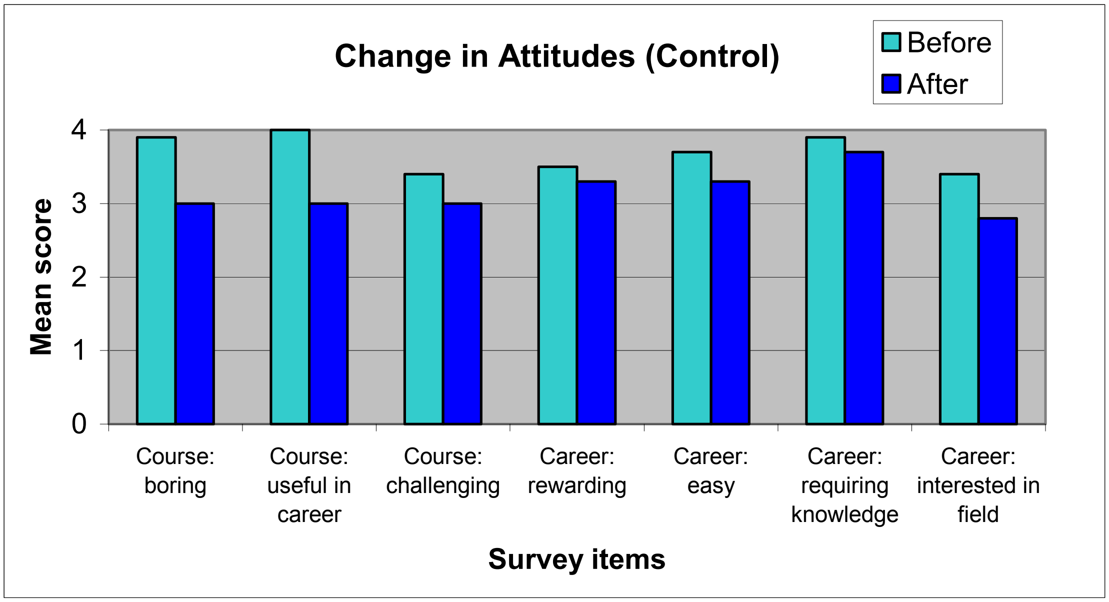

Figure 6-6. Before and After Attitude Scores for Control Class.

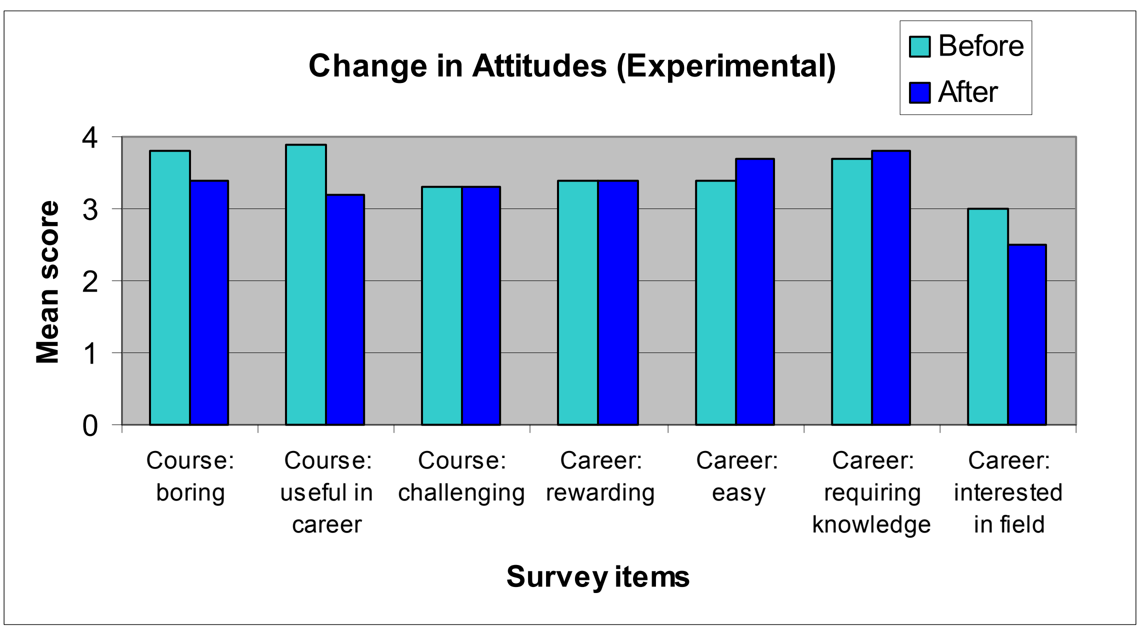

Figure 6-7. Before and After Attitude Scores for Experimental Class.

Both classes had less positive attitudes toward the course after completing it. The attitude changes toward the career field differed between the two classes; the students in the control class had less positive responses to the first three items regarding the career field after taking the course, while the students in the control class had slightly more positive responses after taking the course. In both classes, the less positive responses to the survey item "interested in working in this field" after taking the course probably reflect the fact that many students initially did not know enough about transportation engineering to decide if they were interested in working in this career field, so they responded neutrally or somewhat positively.

6.2.3 End-of-course Attitude Measures

Figure 6-8 shows the mean end-of-course attitude scores for the control and experimental classes. These scores were compared using the t-test for independent samples (see Equation 1). With 52 student responses in the two classes, a t-value of at least ±2.011 would indicate a significant difference between the classes at a 95 percent confidence level; the actual values for the individual questions ranged from –0.306 to 0.414. Although the experimental class responded slightly more positively to the first six survey items and slightly less positively to the last question, the t-values indicate that the differences between the two classes were not significant, or in other words, that they could be explained by chance variations rather than by the treatments.

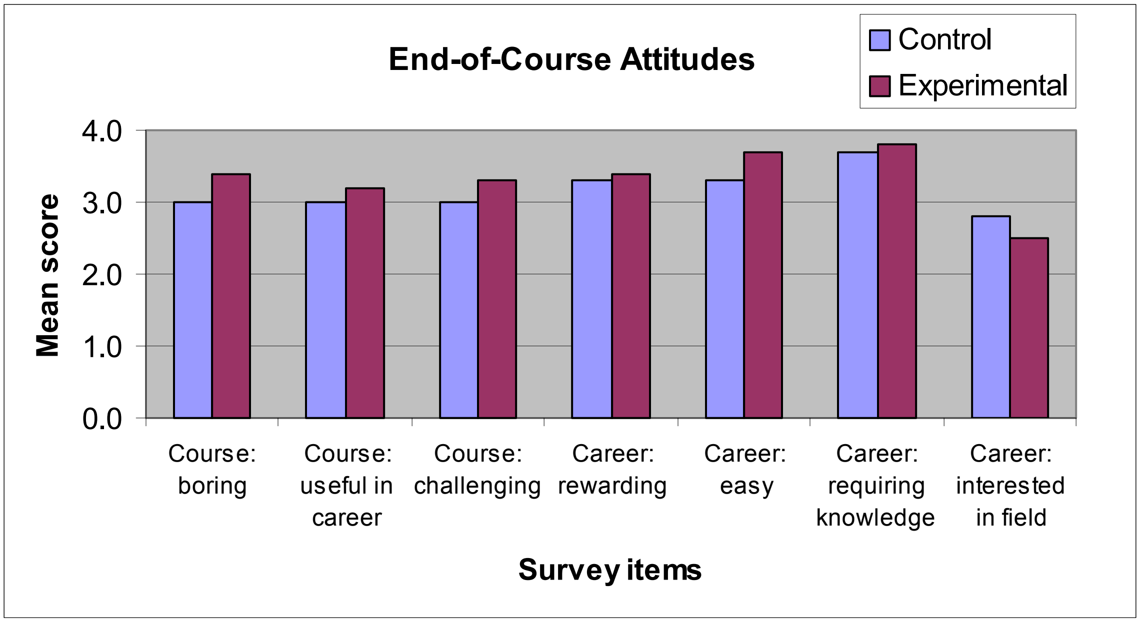

Figure 6-8. End-of-Course Attitude Scores.

The IDEA survey summary results also included measures of teaching effectiveness and ratings of progress on relevant objectives (i.e., those I had designated as "essential" or "important"). Table 6-5 describes the results of this survey for the control and experimental classes.

Table 6-5. Descriptive Statistics for IDEA Summary Scores.

Measure	*Control Class*			*Experimental Class*		
	Mean (Raw)	*SD*	*Skew*	*Mean (Raw)*	*SD*	*Skew*
Improved student attitude	3.6	0.9	-0.79	3.8	1.2	-0.91
Excellence of teacher	3.4	0.9	-0.06	3.9	0.8	-0.39
Excellence of course	3.6	0.9	-0.59	3.5	0.9	-0.34
1. Factual knowledge	4.0	0.7	-0.49	4.1	0.7	0.36
2. Principles and theories	3.9	0.7	-0.32	3.9	1.0	-0.62
4. Professional skills	3.9	0.8	-0.23	4.0	0.8	-1.10
9. Use of resources	3.5	0.9	-0.27	3.6	1.1	-0.26

The student responses to the IDEA survey item, "As a result of taking this course, I have more positive feelings toward this field of study," seem to contradict the responses to the survey items described previously. Of the students who responded to this question, 65 percent in the control class and 71 percent in the experimental class chose answer 4, "more true than false," or 5, "definitely true." For the control class, this item implies that in general the students were more positive about the field after taking the class, while the other items imply that they were less positive about the field. Perhaps the students' interpretation of the IDEA survey item differed from their interpretation of the other attitude survey items.

In general, the control and experimental classes responded very similarly to the items summarized in Table 6-5. The only item on which there was a difference between the classes of more than 0.2 points was the rating of "this instructor as an excellent teacher," to which the experimental class responded more positively.

6.3. Student Feedback

Several of the students in the control class felt that the teaching methods needed improvement, based on their comments on the IDEA survey. A startling 49 percent of them agreed that the course was boring, according to Table 5-11, and only 14 percent disagreed. Of the students in the experimental class who completed the extra questions on the IDEA survey, only seventeen percent agreed that the course was boring, and 44 percent disagreed. While the percentage of students completing these questions was not large enough to be very confident in the overall responses, it is a much more positive trend than that of the control class.

The survey comments from the experimental class regarding teaching methods were generally positive, although one student expressed the opinion that the in-class exercises were not helpful. On the mid-term exam, I also included two bonus questions which asked the students to agree or disagree with two statements about the in-class exercises: (1) "the exercises in class (during lectures) help me understand the course material," and (2) "the in-class exercises are a waste of class time." Twenty-three percent of the students strongly agreed that the exercises were helpful, and 60 percent agreed, while only three percent (i.e., one student) disagreed. Similarly, 30 percent strongly disagreed that the exercises were a waste of time, and 55 percent disagreed, while five percent agreed. In other words, halfway through the course, a large majority indicated that the exercises were both useful and not a waste of class time. This informal survey was, of course, part of an exam and thus may have been skewed toward more positive responses.

VII. Conclusions

The objectives of this research project have been met. I developed and tested experimental undergraduate curricula for highway design and traffic engineering using active-learning methods. I also collected data in an educational experiment that enabled me to assess the relative effectiveness of two teaching methods, the traditional lecture and the lecture with active-learning interludes, with regard to student performance and attitudes. In an attempt to conduct a scientifically valid experiment with clear results, the changes made to the curriculum in CE3050 were purposefully minor. The only difference between the control curriculum and the experimental curriculum was that the experimental curriculum included short exercises and discussions as active interludes within the lectures. It is encouraging that these minor changes appear to have had a positive effect on student learning. Students in both CE3050 and CE405X responded positively – in some cases enthusiastically – to the experimental active-learning approach.

7.1. Summary of Experimental Results

The results of the experiment in CE3050 indicate that the active-learning approach adopted in the experimental class did have a positive impact on student performance as measured by exam scores. The experimental treatment appeared to have a positive effect on the post-test scores for the first set of learning objectives. Although the mean score on the post-test for the second set of objectives was lower for the experimental class than for the control class, the difference was attributable to chance variation rather than an effect of the treatment.

It appears that the thinking processes associated with course learning objectives may be a factor in the relative effectiveness of the experimental teaching methods. The methods seemed to be most effective with objectives involving representation or a combination of selection and synthesis. Since most objectives in CE3050 involved more than one type of thinking process, this conclusion is tentative and should probably be examined further. Another explanation is that the level of participation dropped from the first half of the course to the second half of the course.

No differences in the effects of the teaching methods were apparent between genders, although both classes were both comprised primarily of male students; females made up 22 percent of the combined classes. The majority of the students (33 in each class, or 85 percent of the total) were juniors and seniors majoring in civil engineering, and their performance appears to have been affected positively by the experimental teaching approach. It is interesting to note that of the students ranked in the top half of their class, those in the experimental class performed better than their counterparts in the control class, while there was no significant difference in the performance of the students ranked in the bottom half of their class. This implies that the better students were also more responsive to active learning methods. It is difficult to say whether their performance was more affected because they participated more in the active learning exercises or because the exercises were more useful to them than to the other students.

The results in terms of student attitudes toward transportation engineering did not show a significant difference between the control and experimental classes. The students in the experimental class did indicate slightly more positive attitudes at the end of the course than the control class, however, and when grouped into yes and no answers (instead of a five-point scale), the differences are more pronounced.

7.2. Curriculum Recommendations

There were no obvious drawbacks to the experimental curricula that were developed for CE405X and CE3050. The exercises and discussion topics were not difficult to develop or to use; in several cases, examples that I presented to the control class were easily modified into active interludes for the experimental class. Exercises and discussions generally required more class time than lecturing alone, but not to such an extent that content was removed from the course. The exercises also did not require additional technology or much instructor time.

On the positive side, the active-learning-based approach appears to have improved overall student performance. Students were also less frustrated by this approach than by lecturing alone, based on the survey results, and a large majority of the students in the experimental course indicated at mid-term that the in-class exercises were useful and not a waste of class time.

I recommend that exercises and discussions similar to those in the experimental curricula be used in other civil engineering courses. Although this study focused on transportation engineering classes, the students were representative of the upper-class civil engineering majors at WPI, so active-learning exercises would probably be successful in other types of civil engineering courses as well.

One improvement that should be made to the teaching approach taken in this project is to reward participation in some way so that students are encouraged to take part in the exercises and discussions. For example, an instructor could occasionally assign participation grades by calling on a student at random or collecting student papers after an exercise. The emphasis would need to be on active participation, not necessarily correct solutions.

7.3. Further Research

As with most research studies, the results have led to additional questions. In this case, questions that might merit further study include:

- Is an active-learning approach more effective for particular types of objectives, topics, or thinking processes?

- Do certain subsets of a class respond better to the active-learning approach, i.e., are there differences between genders, among class years or majors, or among personality types?

- Is the difference in the effectiveness of the active-learning approach between students in the top and bottom halves of their classes due to the students' level of participation in the exercises or to some other factor?

- How can the ideal amount of in-class active learning be determined for a particular course, to maximize student learning and positive attitudes? We intuitively know that there must be some balance between lecturing and interaction, but assessing that balance is still somewhat of a mystery.

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