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Analyzing the growth of the critical thinking skills of college calculus students

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Analyzing the growth of the critical thinking skills of college calculus students

by

Cymbelene Ann Forbes

A dissertation submitted to the graduate faculty in partial fulfillment of the requirements for the degree of DOCTOR OF PHILOSOPHY

Major: Education (Adult and Extension Education)

Major Professor: John P. Wilson

Iowa State University

Ames, Iowa

1997
This is to certify that the Doctoral dissertation of
Cymbelene Ann Forbes
has met the dissertation requirements of Iowa State University
DEDICATION

I dedicate the completion of this dissertation to my parents, Algenon Wilson and Rachel Sorenson Forbes, who instilled in me a strong code of ethics, a deep understanding of the importance of social justice, and a great respect for the common man and the natural environment in which he lives.
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CHAPTER 1. INTRODUCTION

In alluding just now to our system of education, I spoke of the deadliness of its details... It is a system of despair.

Emerson

It appears that in a century not much has occurred that would alter the above essayist's view. The cover of the September 16, 1991 issue of Time magazine is illustrated with the picture of the recently appointed U. S. Education Secretary, Lamar Alexander, and the question, "Can This Man Save Our Schools?". In this issue, Shapiro (1991) pointed out that since the era in the 1950's of "Why Johnny Can't Read", Americans have questioned the quality of their schools. An ABC television show sent hidden cameras into what would be described as middle class schools. Resulting footage showed students carrying guns, principals reduced to helpless inertia, and entire class periods where students spent the time yelling and aggressively attacking each other. And still there exists a focus of anxiety and even desperation, that goes beyond teachers, curriculums, or budgets, and centers on the concept of the failure of public education as an entire system. The malaise of the 1980's and the failures that came from mere tinkering with the existing public education system have now spread to cover America's system of higher education as well (Fiske & Callan, 1993). This anxiety, fueled by reports of enormous classes, inaccessible professors, athletic scandals, price
fixing, and excessive billing for research raises doubts about how well higher education is fulfilling its public trust.

The itemized lists of shortcomings of the U. S. educational system and correlated lists of recommendations continually cited in a plethora of national commissions could be easily summarized. One good reason for not doing so, is their dubious utilitarian value as discussed by Goodlad (1983a). Goodlad stressed that the factory approach (the production model) is not useful for developing effective change strategies. This model, which sets an agenda, endeavors to justify it with collections of quantitative data, and results in lists of recommendations, does not include an ecological perspective. Goodlad (1983a) stated this approach doesn't look at the culture of schools—what goes on between the input valve and the output spigot. Goodlad pointed out that treating a frozen water pipe in this fashion would have a similar disastrous effect. Mandates, testing requirements, standards, or other external pressures which ignore the interaction of elements (especially human) within and around schools is most unlikely to effect change.

Another reason for not itemizing these recommendations is that these reports tend to be very narrow in perspective. A more telling approach is to analyze the shortcomings of the U. S. education system in terms of their breadth.
Failure in Terms of Academic Achievement

Nothing in education is so astounding as the amount of ignorance it accumulates in the form of inert facts.

Henry Brooke Adams

Reports of declining scores throughout the nation on the Scholastic Aptitude Test (SAT) again surfaced in 1991, with small improvements shown in 1992. (The real significance of this fact is discussed later in this paper.) A survey of the literature reveals a pervasive need for remedial programs. This fact will not disappear by calling remedial education the "curse of higher education" (Promises to keep, 1983, p. ix) and declaring that higher education never should have started it and ought to get out of it. Secondary education students are not academically prepared for course work in tertiary institutions (Hollingsworth, 1982; Pearlman, 1977; Promises to keep; Wright & Cahalan, 1985). Scott (1987) found that although the University of California system admits only the top 12 percent of graduating high school seniors, half of all new freshmen are placed in non-credit remedial courses, and in 1982, this system spent $5.5 million in remedial programs. This makes a statement about the students from the remaining 88 percent who are candidates for other post-secondary education programs. From their national survey of 511 colleges, chosen from 3,238 institutions, Wright and Cahalan found in 1983-1984, 71 percent offered courses in remedial
mathematics and 25 percent of all college freshmen took one or more courses in remedial mathematics. And the problem of unprepared students is growing, not only in sheer numbers of students, but in demographic patterns (Conciatore, 1991). The term underprepared now applies to very bright students for whom English is a second language, and adults who need updated skills for the changing job market where there is no longer a dichotomy between thinking and making jobs. The educational system is not meeting these students' needs. The Public Concern Foundation's July 1, 1990 issue of The Washington Spectator quoted statistics from the Congressional Record:

Comment in the Record points out that "large percentages of students do not perform very well [beyond minimum basics]. Only 6 percent of 17-year-olds can solve a multi-step math problem and only seven percent are able to draw conclusions from detailed scientific knowledge. Only 20 percent can write an 'adequate' letter applying for a job demonstrating a little critical thinking", according to a National Education Association report. A study by the Educational Testing Service compares the math and science performance of 13-year-olds in the U.S. with those from 11 other countries and two Canadian provinces. The American students performed at the very bottom. (p. 2)
These statistics don't even touch the issues of illiteracy or the costs of increasing school dropout rates. G. Lee Thompson, Chairman and CEO of Smith Corona (cited in Landsman & Harbaugh, 1991), stated:

It is sadly ironic that the nation with the greatest infrastructure in the world, a country with the most libraries and computers, ranks near the bottom of Western nations in literacy. Even among high school and college students, communications skills are poor: less than half of high school seniors read at levels able to carry out complex tasks; 80% have inadequate writing skills. (p. A8)

Francis (1991) quoted from a report entitled: "The Unfinished Agenda: A New Vision for Child Development and Education". It was prepared by the Committee for Economic Development (CED), a group of 250 corporate executives plus some university presidents. Some of the statistics Francis cited are:

Every class of dropouts--the youths who leave United States schools in a single year--earns about $237 billion less than an equivalent class of high school graduates during their lifetime. As a result, the government receives about $70 billion less in tax revenues. And 82 percent of all Americans in prison are high school dropouts. It costs an average of $20,000 to maintain each prisoner annually. (p. 8)

Francis noted that while business leaders worry about America's industrial and technological capacity to progress being stymied by a lack of educated workers--the vital human
resource needed for America to remain competitive in the
global market, they are also concerned about the social
costs of a lackluster educational system. "As patriots,
they are also worried about the stability of U.S. society if
a large proportion of the public is unable to read properly
and ignorant of governmental affairs" (Francis, p. 8).
Francis also quoted the CED report on this issue:

Our society has undergone profound economic and
demographic transformations, but the social and
educational institutions that prepare children to
become capable and responsible adults have failed to
keep pace. Unless we act swiftly and decisively to
improve the way we invest in our most important
resource--our nation's children--we are jeopardizing
America's survival as a free and prosperous society and
condemning much of a new generation to lives of poverty
and despair. (p. 8)

When considering education at the university level, in
righteous self-defense members of the higher education
community will be inclined to say their institutions turn
out successful graduates. But where is the documentation
demonstrating excellence? Where are the great thinkers,
artists, or composers? Where are the engineers with
creative, cost-effective solutions to prevent destructive
environmental practices? Where are the pioneering medical
researchers with the wills, and the ability to ethically
research the causes of breast cancer in women? And these
expectations for our college graduates in the face of
reality, though appropriate, are unfortunately unrealistic.
A recent report for the Education Testing Service of
Princeton, New Jersey found half of all four year college
graduates couldn't understand a bus schedule, only 3 percent could write a brief letter to explain a billing error, and only 4 percent could contrast views about new car technology made in newspaper editorials ("Quality Of College," 1994). Success can be viewed as failure.

**Failure in Terms of Social Equity**

Education then, beyond all other devices of human origin is a great equalizer of conditions of men—the balance wheel of the social machinery.

Horace Mann

"How noble the dream, how ignoble the modern reality" (Shapiro, 1991, p. 54). Appleman (1991) wrote about one of her students from Carleton College, Michael Lach, who had completed a year of teaching as one of the recruits for Teach for America (TFA), a national, private, nonprofit teacher corps, modelled after the Peace Corps, which recruits graduates from the nation's top universities to teach for two years in some of the nation's most impoverished schools. Appleman described the high school where Michael was assigned:

The school, he reports is in dilapidated condition—graffiti-covered walls, peeling paint, collapsed ceilings. It is also woefully ill-equipped, not just for fancy science experiments, but for everyday teaching needs. For example, Mike had to buy his own chalk and paper and pay for his own duplicating. (p. 19)

Even if this school was a freak of the system, an isolated case, it is one school too many. But this school is not an isolated case, and documentation in Jonathon Kozol's book,
Savage Inequalities: Children in America's Schools, (cited in Maeroff, 1991), and in an Educational Testing Service report, "The State of Inequality" (Walters, 1991d) attests to this fact. Another indicator that glaring inequities are pervasive is the willingness of the private sector to fund an organization with a mission such as that of TFA, which in desperation mode, initiates change efforts by circumventing governmental offices, established teacher education programs, and any other institutions representing the status quo.

Kozol (cited in Walters, 1991a) reflected on the disheartening fact that such injustices are not only tolerated, but supported by parents who wouldn't dream of allowing a Little League baseball game where the privileged kids had baseball mitts and the poor kids had to play with their bare hands. Kozol (cited in Walters, 1991a) said, "It's selfishness" (p. 13). Kozol continued, "Despite a lot of rhetoric about equal opportunity in America, most Americans want their child to have a better than equal opportunity, which means inevitably that they want someone else's child to have a less than equal opportunity" (p. 13). A case in point is the "creative financing" advice given to wealthy parents by companies which are in business for just the purpose of aiding wealthy parents in hiding income so their children will qualify for federal aid for tuition to prestigious schools. Gaudiani (cited in Ostling, 1992)
stated, "It's wrong for us who have an education and who have all the privileges to teach each other how to cheat" (p. 65). Gaudiani drew this analogy:

It's easy for a lot of people to condemn youngsters who walk into stores that have been blasted open and take things that don't belong to them. Everyone calls that looting, and it's certainly illegal and not appropriate. But when people with $350,000 incomes shelter that by transferring assets to grandparents and reporting $41,700 and then qualify for $12,000 in aid, that's another form of looting. (p. 65)

The U. S. government spends around $226 million per cadet at West Point and around $3,000 per student at Oglala Lakota College (for native Americans).

The shameful reality is that the U.S. education system reflects a national philosophy of protecting the status quo where the Haves and Have Nots are invidiously kept separate.

**Failure To Develop Citizens Who Can Think Critically**

Nations have recently been led to borrow billions for war; no nation has ever borrowed largely for education. Probably no nation is rich enough to pay for both war and civilization. We must make a choice; we cannot have both.

Abraham Flexner

Within the past thirty years, the U. S. has initiated and heavily financed two military invasions in foreign countries. Both wars resulted in horrendous losses in terms of human life and suffering, and scarring, long term environmental damage. Historical review has not been positive about the need for, or the results of, the earlier
war. It is doubtful that historical review will be any more positive about the most recent war.

Major U. S. news stories have centered around the words "cover-up" and "scandal". There has been the Watergate affair and a U. S. president was forced to resign. There have been the Iran-contra cover-up, the saga of the governmental bail out of the savings and loans financial institutions linked with the Keating Five scandal, and the Bank of Credit and Commerce International scandal with accusations of feet dragging by the Justice Department. A president's lack of will to rise above the politics of Supreme Court appointees led to an embarrassing public fiasco where all parties involved, and indirectly the groups they represented, lost credibility. And recent press articles have strongly questioned the ethics of the U. S. president and his wife.

Bali, Indonesia has a perfect natural water system used to grow some of the best rice in the world. The U.S. has subsidized Indonesia to buy up this country's stockpiles of the banned pesticide DDT. Incidents like this led two Democratic Congressmen, Senator Leahy (D-VT) and Representative Synar (D-OK) to introduce The Circle of Poison Prevention Act of 1991 (S.898 and H.R. 2083), which among other stipulations, would prohibit the export of pesticides that are not registered for domestic use, or do not have a residue limit, and permit foreign governments to
refuse to import particularly hazardous pesticides (*Action Access*, p. 7). It's not so noteworthy that such a law was proposed. What is extremely noteworthy, however, is that there exists a need to mandate such ethical practices. And nothing seems to change. In 1994 the scientific data documenting the serious harmful affects of smoking spurred a flurry of legislation against the powerful tobacco companies. The federal government's response was to have the U. S. Department of Agriculture allocate tax dollars to the tobacco companies to be used to encourage sales of tobacco in potentially lucrative foreign markets.

The lifestyles of a large proportion of American society tend to be lives of individual conspicuous consumerism, driven by short-term desires for immediate gratification. We do not have a global perspective—certainly not about how our actions affect the world community, but not even about how our actions affect other citizens of our country, or even our neighbors.

The one common denominator to all of these noted incidents is that most of the people involved in these actions and decisions are products of the American education system. This system was a part of this failure in critical thinking and ethical leadership.
A Call for Change

The breadth of failure in the U. S. educational system is ample reason for a call for change. However, the tenets of androgogy suggest that it is important to identify the type of changes needed to be made, who the change agent(s) should be, and whether these changes need to occur at the macro-level of social institutions, or at some micro-level, perhaps even at cites where individual learning is taking place. And to talk about implementing change it is necessary to consider how social problems are defined, because these definitions directly affect the success of any change efforts. These definitions lead to perspectives that determine how successful change efforts can realistically be expected to be.

Problem Statements

A review of the literature supports the following problem statements:

1. There is a breadth of failure in the American education system—in terms of academic achievement, in terms of social equity, and in terms of graduating citizens with the ability to think critically and act ethically.

2. Historically, socially, and culturally, the
cards are stacked against reform of the American educational system at any macro-level, either governmental or institutional.

3. Students in the American education system do not learn to think critically resulting in large economic and social costs.

4. Trained educators do not teach their students how to think critically because many teacher training programs do not present models of alternatives to traditional passive learning formats, nor do they expose future teachers to any aspect of critical thinking. The same is true for many tertiary level educators because they themselves have never experienced learning in any type of active learning environment.

**Research Questions**

These statements lead to the following research questions:

1. Is it possible to implement a change at the micro-level (locations where teachers and learners are gathered) which will have a positive effect not only on learners' achievement, but on the growth of their critical thinking skills as well?

2. In conjunction with #1 above, is there a teaching
model with a strong theoretical base that will facilitate the growth of students' critical thinking skills (in terms of both dispositions and cognitive skills) across disciplines, ability levels, and gender?
A Discussion About Implementing Change

There is no more delicate matter to take in hand, nor more dangerous to conduct, nor more doubtful of success, than to step up as a leader in the introduction of changes. For he who innovates will have for his enemies all those who are well off under the existing order of things, and only lukewarm supporters in those who might be better off under the new.

Niccolo Machiavelli

Biklen (1983, chap. 3) discussed how social problems are defined and stressed that such definitions are not singular or objective; they come from the perceptions of the eye of the beholder. Biklen noted that the large number of students who drop out of school in major urban areas may be viewed as a problem to educators, parents of those students, and to the students themselves, but not to the affluent college bound students or to their parents. Manufacturers of unsafe cars, absentee landlords who charge extortionist rates for rat-infested slum dwellings, doctors exploiting Medicare options, and manufacturers of hazardous chemicals are all perceived as operating within the law, and of no problematic consequence (Biklen). Obviously, not because this is truly the case, but because such a perception is a reflection of the values, and a codification of the self-interests of the dominant classes of society.

Biklen (1983) discussed five models used to define social problems. Three of these have relevance to
educational reform. The culture of poverty model, touted as having a caring perspective, is characterized as "blaming the victims" (Biklen, p. 37). Biklen stated:

It suggested that poor people, cast into bad circumstances, learned a culture of poverty, replete with laziness, defeatism, irresponsible family behavior, sexual promiscuity, ignorance and violence. And equally importantly, it ignored altogether the possibility that people were out of work because there were no jobs or that poor children did not succeed in school because they faced racism and other forms of discrimination on a daily basis. Indeed the "culture of poverty" served both as the dominant social problem and the chief means of justifying the status quo. ...According to this viewpoint the way to solve social problems was by creating special remedial programs to change individuals who had been or likely would be socialized to the culture of poverty. Social programs took such forms as job training and retraining, compensatory education, Headstart, community mental health services, and public housing. (p. 37)

Using this model, no attempts are made to make structural changes in society to alleviate the conditions that create a need for such short-sighted measures. This is a convenient model. It says "these people" are their own worst enemies. They're different - needing to be brought "into the fold". It is a model of self-interest for people with money or power which exonerates them from any responsibility for the conditions of those less fortunate (Biklen, p. 38). It is a model that excludes the possibility that changes need to occur within social structures and economic systems to alleviate societal prejudice and institutional discrimination.
Another model for defining social problems is the technocracy model. This model asserts that social problems surface when people cannot keep up with or adjust to technological demands or when technology fails to keep pace with needed changes (Biklen, p. 40). Discussing change under this model Biklen stated:

Technicists believe that such goals can be achieved through rational, bureaucratic planning. Their planning and problem definition activities incorporate a range of computer associated and technocratic words like feedback, interface, variables, component, capacity building, output, input, indicators, impact (as a verb), yields, and tolerance factors. ...When technicists define social problems, they generally isolate social conditions and define problems in terms of specific conditions and put forth narrow, technical solutions. Their approach deems narrow technical solutions as "practical" and views a broader social analysis which recognizes the interrelationship of wide ranging conditions and problems as "impractical" or "romantic". (p. 40)

Under this paradigm ignorance is a "problem of a technically weak curriculum" and unemployment is a function of "people and industries in need of some technical retuning" (Biklen, p. 40). Biklen continued:

One critic of the technocratic ideology warns that American education has given itself over to propagating the technocratic viewpoint. This is particularly apparent in so-called "engineered classrooms" for behavior problem children. However, as Bowers notes, it is also true for typical children, youth, and even for their teachers, all of whom learn that the goal of education is not so much to gain broad knowledge as "specific competencies." (p. 41)

The ideal education would foster the idea that the beliefs and practices of one's society must always be subjected to rational scrutiny (Biklen). But Bowers (cited in Biklen,
1983) states competency-based instruction, on the other hand, "reflects a revolutionary shift" to a "technocratic consciousness" (p. 41). Thus the individual who learns this body of knowledge becomes a "component" or a "product" of the system (Bowers, p. 41).

Biklen concluded by saying:

Like the victim blaming ideology of problem identification, the technocratic model attributes causation for social problems to environmental conditions (that is, a poorly engineered social environment). What is unique about this model is its seemingly antiseptic quality. It conjures up images of malfunctioning technological systems rather than the profiteering of one group of people from another or the insensitivity of one group to another. It seemingly neutralizes the human element altogether. Through this model, we lose sight of people, whether they are victims or victimizers. (p. 41)

A third model for defining social problems is the model of social and economic democracy. Biklen described this model as follows:

At the risk of oversimplifying, the problem is not one of poverty, but of enormous wealth. The problem is not one of gaps or cracks in an otherwise fine system but of a system which perpetuates prejudicial views concerning race, sex, age, and disability. The problem is not one of incompetence but of barriers to education, jobs, and power. (p. 41)

Biklen continued:

According to this thesis, a relatively few number of people in the United States earn extraordinarily large amounts of money - hundreds of thousands of dollars per day and pay little or no taxes on these gains. Such practices have been called welfare for the rich. ...But more to the point, people with wealth can invest in so-called tax shelters, such as oil drilling operations, and thereby reduce their taxes dramatically. ...To demonstrate the incredible gulf between the wealthy and the poor, Stern cites one Brookings Institute study which found that of "77.3
billion in tax 'handouts', just over $92 million goes to the six million poorest families in the nation, while 24 times that amount ... goes to just 3,000 (wealthy) families. In one year, the government paid out 14.7 million dollars for the food stamp program while providing five times that amount in "tax welfare" to families that make more than $100,000 per year. (p. 42)

In other words, the well-to-do do well. A telling and specific example appeared in a newspaper article from the Reuter news service. Then President Bush legally avoided paying most state and local taxes since taking office by taking advantage of tax laws in three places of residence ("Magazine: Bush", 1991). As a result the Bush family cut their tax bill to 29.5 percent of their income, while an American family with an adjusted gross income slightly over one-tenth of the Bush income paid 37.7 percent in taxes ("Magazine: Bush"). Also, Mr. and Mrs. George Bush paid only 16 percent in federal income taxes on $1,329,580 due to the cap on Social Security contributions and various investment deductions, while in 1991 a couple making $53,000 paid about 28 percent (Goodgame, 1992).

An assertion of the social and economic democracy model is that social problems are fostered not only by economic forces, but by social institutions that respect those factors (Biklen, chap. 2, 1983). This reasoning explains why historically any types of educational change have been superficial remedies that fit into the culture of poverty model (like remedial education) or the technocracy model (like the push for computer assisted instruction), and not
structural changes that would threaten the continuation of a system that has been beneficial to those who have wealth/power. And even these palliative remedies are implemented haphazardly as fads without a sound research base or evaluation process, as in the case of computer assisted instruction, or slowly and grudgingly, as in the case of remedial education.

Remedial education is viewed as a pariah (Roueche & Kirk, 1973, chap. 5; Vaughan, chap. 4, 1983). Yet the need for remedial programs is growing rapidly with expanding demographic patterns. Already mentioned are the bright students for whom English is a second language, and adults who need new job skills to meet the demands of a rapidly changing job market. But demographer Hodgkinson presents other significant data that will radically effect the American education system. Hodgkinson (1985, p.3) stated that every day in America forty teen-age girls give birth to their third child, and to be the third child of a child is to be very much "at risk" in all areas of development. Government spending for poor children has declined during the past decade and half of the poor in the U.S. are children, so over two million children are actually at risk from birth (Hodgkinson). By the year 2000, America will be a nation in which one in three of us are non-white (Hodgkinson). What is marching toward the American education system is "a group of children who will be poorer,
more ethnically and linguistically diverse, and who will have more handicaps that effect their learning" (Hodgkinson, p. 7).

Obviously more than remedial programs is needed. Yet on April 18, 1991, when then President Bush, who asked to be called the "Education President", announced AMERICA2000: An Educational Strategy, it was correctly emphasized that it was a "strategy", not a federal program. President Bush announced the "strategy" in a speech where he said, "There will be no renaissance without a revolution" (AMERICA2000, 1991, p. 51). But the implementation of the six national education goals was far removed from any revolution involving strategic structural changes to the system. It was merely a "strategy", utilizing the business as usual technocracy model, emphasizing a few "fixes" while maintaining the status quo. No mention was made of addressing real symptoms of a failing educational system, much less any plans to implement needed structural changes to a society that nurtures gross social inequities and condones the educational inequities that exist as a reflection of this nurturing.

The two most prominent implementation elements of the President's plan were to give parental choice in choosing schools, and to heed the research data that shows no correlation between dollars spent and educational success (AMERICA2000). As for the research about the correlation
between funding and educational success it should be noted that such research comes from institutions geared to maintaining the status quo. The research does not look at cases where the increased funding actually reached the learners, providing extra resources to specific cites where learning was actually taking place (Walters, 1991d; Heyneman, cited in Anderson & Windham, 1982). Both Walters and Heyneman noted the ambiguity of the efficacy of school physical quality in high-income countries. But Heyneman stated that, "The evidence we have to date would suggest that school quality in low-income countries can explain twice and even three times the level of achievement variance that it can in high-income countries, and the poorer the country in economic terms, the greater the impact on achievement school quality seems to have (r = -.67, p < .001)" (Heyneman, pp. 135-136). It would not be illogical to expect some of the same results if increased funding directly reached the many impoverished education districts in the U. S.

Choice, of course, will work even better for the Haves of society who already have the experience and means to make the system work well for them as it always has. But for those who have been disenfranchised in the past, Choice will leave them more so. In the game of educational musical chairs, someone has to lose. "And certainly the last student stuck in a failing school will come from an impoverished
background" (Shapiro, p. 60). Former St. Paul, Minnesota school superintendent, David Bennett, now runs private Tesseract Schools for profit. Even though unrestricted Choice would be a boom for his business, he was frank about its effect when he stated, "No matter how you dress up a voucher system, the poverty kids will end up with the short end of the stick" (Bennett, cited in Shapiro, 1991, p. 60).

Recently President Clinton was lauded from all sides of the political spectrum for his strong use of the presidential bully pulpit to rally national support for education. In his second State of the Union address he issued a call for a "national crusade" with a "10-step" plan to overhaul the nation's schools (Stout and Frisby, 1997). But many of the points such as increasing Pell Grants, the Hope Scholarship credits, tax deductions for tuition, and tax-free IRA withdrawals have more to do with easing the pressure on parental pocketbooks than any structural changes (Stout and Frisby). The 26 percent increase in the GOALS2000 program (for funding state initiatives to develop uniform standards for student achievement), the push for computers in schools, and the Reading Corps (putting volunteers as reading tutors in classrooms), have merit, but are also "patches", not structural changes. And a major concern as stated by David Crandall, president of The Network Inc., a nonprofit educational and retraining group is that most of the president's proposals do not address a
key problem in schools today which is the retraining of teachers (Goodrich, 1997).

Paul (1984) makes a blunt observation about increased funding for educators:

In California today, Blue Shield pays an average of $6000 to the chief surgeon at a two hour coronary by-pass operation. A surgeon who performs 200 by-passes a year—a light to moderate load—can easily gross more than $1,000,000. (p. 21)

Paul wondered why society instead doesn't expect more dedication and commitment of our heart surgeons?

Roger Smith, former CEO of General Motors for a decade when GM lost ten percentage points of the U.S. car-market share, is rewarded by getting a $26,000 a year seat on the GM board (Witteman, 1992). Each time he actually attends a board meeting he gets an extra $1,000, and he earns an additional $12,000 a year for sharing his thoughts with the other members of the finance committee (Witteman).

It does seem that those responsible for educating our nation's students are the only ones who don't rate financial support.

Nonpartisan policy institutes have criticized President Clinton's college tuition tax credit plan as a middle class tax cut (Baldauf, 1997). Only 8 percent of the lower income students go to college compared to 87 percent of middle to upper income students (Baldauf). Looking at family incomes of those students who received financial assistance for the poor, two-thirds of the families earned less than $9000 a
year and very few earn enough to itemize deductions or receive tuition tax credits (Baldauf).

Thus there is reason for pessimism about the ability of government to implement long-term structural change. If nothing else there is the great difficulty of breaking the massive inertia of tradition to get changes to occur at more than the usual glacial pace.

But Paul (1984) is convinced that there is really no national will to change the educational system because it is self-serving. Analyzing American education from an historical perspective Paul stated that American schools, following the Harvard tradition of religious inculcation, and separate schooling for the elite and the common people, are secular products with "nationalistic inculcation replacing where it does not buttress religious indoctrination" (p. 10). Paul stated, "In both cases, however, there has been virtually no place for critical analysis or independent thought" (p. 10). Any individual efforts to do so have had little effect on reality because these efforts conflict with potent social forces (Paul). Actually the truth of this observation was supported when the Republicans won a majority after the mid-term Congressional elections in 1994. The emphasis for educational change in the Republicans' "Contract for America" was to mandate prayer in public school classrooms. As Paul stated, education serves the dishonorable function
of rationalizing the structure of power in the status quo and the idealization of what in general is viewed as the "American Way" (p. 10).

For whatever the reason, it does seem unlikely that structural educational changes will result from actions taken at governmental levels. But can such changes be expected to occur at the macro-level outside the domain of government?

Senator Howard Metzenbaum (Democrat, Ohio) discussed the duplicity of American business in regards to educational reform (Metzenbaum, 1992). He stated:

What is particularly ironic is that American business leaders chronically decry the state of American education. Corporate CEO's state that an educated, literate work force is the key to American competitiveness. They point out their magnanimous corporate contributions to education in one breath, and pull the tax base out from under local schools in the next. (p. 19)

Senator Metzenbaum cited study after study showing how property-tax abatements to corporations have seriously adversely impacted local schools. One glaring example is the recent battle between Arlington, Texas and Ypsilanti, Michigan to save their General Motors plants. Arlington won, but the cost? GM received tax breaks between $7 million and $10 million, most of which would come straight out of the pocket of the local schools (Metzenbaum). Another case, cited by Metzenbaum from his own state, involved a hotel and office building which was given a 100 percent property-tax exemption, which cost Cleveland schools $4.8
million and was part of the $100 million that corporations have depleted from the Cleveland school system (Metzenbaum). Metzenbaum stated that "in self-interest businesses take out essential revenues needed to educate our kids - and they call it economic development" (p. 19).

Corporations have seen their taxes decline by about a third in the past few decades while the middle class pays 32 percent more than it did 20 years ago (Ehrenreich, 1994).

In self-interest, American business lobbies for the status quo. So much for education in partnership with business.

There is validity to the claim that colleges of education are not open to change. Fiske (cited in Walters, 1991c) spent three years researching grass-roots revolutions going on in educational institutions. He planned to write a chapter on a college of education that was successfully preparing teachers for the schools of the future, but his search proved futile. "Teacher education is the big black hole in the movement to create smart schools" (Fiske, cited in Walters, 1991b, p.13).

Goodlad (1983a; 1983b) studied 1,016 classrooms in 38 schools, with data collection teams of 20 people spending approximately 20 days in each school. Due to stagnant teacher training programs, teacher isolation from peers, administration bureaucracy more concerned with declining SAT scores and Gallup polls than with the actual conditions in
their local schools, "the cards are stacked against innovation and change in American schools" concluded Goodlad (1983a, p. 463). In the areas of "how" and "what" regarding teaching and learning, there is a bland sameness—schools with consistent variability in other areas such as school climate, teacher/principal relations and school/community relations could not be differentiated in these two areas (Goodlad, 1983b).

It appears that it is unproductive to expect educational change to occur at any macro-level, either governmental or institutional. This leads to the conclusion that expectations for educational change should focus on change at the micro-level--within specific settings where teaching and learning is occurring. Now the questions become, what type of micro-level change, and what should be the goals of this change? A review of the literature supports the idea that the climate of educational settings should change from one encouraging instructor controlled passive learning to a transactional environment that encourages mutually controlled active learning. Also supported is the statement that the goal of any educational process should be to improve learners' critical thinking skills.
The Need To Teach Students To Think Critically

Education is training in HOW to think rather than in WHAT to think; it is a confrontation, a dialogue between ways of assessing evidence and supporting conclusions.

Emerson Shideler

Many authors join in as Paul (1986, p.1) stated, "the clarion call for critical thinking from kindergarten to graduate school" (Adams & Hamm, 1990; Brookfield, 1988; Cierzniak, 1985; Facione, 1990e; Howe & Warren, 1989; McTighe & Schollenberger, 1985; Norris, 1985; Paul, 1984; Ruggiero, 1988; Walsh & Paul, 1986). Facione (1990e) cited at least twenty authors who have made the case that educating students to be critical thinkers is necessary not just for themselves, but for society in general. Walsh and Paul, and Ruggiero, cited many authors and a plethora of national commissions stressing the pragmatic need to teach students to think critically in order to overcome the crisis of a work force unprepared to compete in a high-tech information age, within the framework of the global economy of the 21st century. The days of the dichotomy between thinking jobs and making jobs are over. McTighe and Schollenberger gave the following statistics:

It is estimated that the information half-life (the time period during which half the information in a field becomes outdated) of certain fields is as short as six years. At present, 55 percent of the nation's workers are engaged in processing and communicating information, and the percentage is expected to increase in the future (p. 4).
Paul (1984) noted that only a small percentage of high school graduates have the same vocational plans as when they entered high school and that within five years of university graduation only a minority of students have jobs in the area of their collegiate major. Therefore, the key to any type of job training lies in nurturing general transferable skills (Paul). Thus, the growing accord "that the heart of education lies in the processes of inquiry, learning and thinking rather than in the accumulation of disjointed skills and senescent information" (Facione, 1989, p.1). A secondary support of this statement is offered by McTighe and Schollenberger (1985) who noted that an analysis of declining SAT scores shows no significant decline in spelling, punctuation, reading recall, or basic mathematics skills, but instead a lack of success on those questions requiring complex thinking skills such as making analogies and organizing concepts.

There is merit to having citizens who are productive units in a society's work force. But perhaps the most salient reasons to teach students to think critically are the philosophical ones. With similarities to the ideas of Paulo Freire, and reflecting the background of John Dewey's educational philosophy, Brookfield (1988) emphasized the idea of praxis—alternating and continuous engagements by teachers and learners in exploration, action, and reflection with the goal of inculcating in students a healthy rational
skepticism (p. 126). Facilitating learning should be geared to empowering students with the ability to scrutinize supposedly universal beliefs, values, and behaviors as being relative - not absolute (Brookfield). Grounded in this facilitation of critical reflection is a global perspective. This is a respect for learners' differences in opinions and beliefs and a willingness to openly analyze alternative ways of thinking. In essence, to encourage students to "stand against the winds of doctrine" (Bryson, cited in Brookfield, 1988, p. 127).

Norris (1985) in his synthesis of research on critical thinking, highlighted this respect for learners. Remarking that critical thinking is not just another educational option, Norris stated:

Rather it is an indispensable part of education, because being able to think critically is a necessary condition for being educated, and because teaching with the spirit of critical thinking is the only way to satisfy the moral injunction of respect for individuals, which must apply to students as well as to anyone else. According to this reasoning, students have a moral right to teaching that embodies the spirit of critical thinking and a moral right to be taught how to think critically. (p. 40)

Paul (1984) stressed the bonus factor of having a nation of people trained to think critically by asking the reader to imagine for a minute that we had had a citizenry sufficiently educated to have decided not to support a war in Vietnam--a savings of some 200 billion dollars. (Not to mention loss of human life, suffering, and environmental damage). Referring to the benefits of teaching students to
think critically, Paul stated:

Then not only would we have a large pool of talent to solve our technical and scientific problems, but we would also have a citizenry with the critical faculties and intellectual wherewithal to recognize and prevent wrongful and wasteful allocations of life, money, and other resources. (p. 22)

Defining Critical Thinking

There is little disagreement among authors about the importance of teaching students how to think, but this is where the agreement ends. "While there is little argument on the name of the game, there is much contradiction and confusion on how to play it" (Thomas & Taylor, 1975, p.1). Lewis and Smith (1993) refer to this problem of definition using Cuban's expression, "conceptual swamp". Defining thinking has incorporated a broad range of topics including Guilford's analysis of intelligence, the classifying of cognitive processes such as Bloom's taxonomy, information processing models like Fletcher's, or problem solving models such as Dewey's (Thomas & Taylor). The variations of thought on critical thinking have included the narrow idea of a product, an end result, while others champion critical thinking as a process (Fulton, 1989). Critical thinking (CT) has been limited to logic, reasoning, and problem solving skills, and broadened to include inquiry, judgement, evaluation, and reflective thought (Fulton; Thomas & Taylor). It appears that the evolution of thought about CT
has led to the conclusion that CT is a process that encompasses both specific skills and strategies for engaging in the process, and the dispositions (the positive attitudes and perseverance) to engage in this process (Fulton; Facione, 1989; Norris, 1989; Walsh & Paul, 1986).

Facione (1990e) employed the Delphi Method using an interactive panel of forty-six experts recognized by professional colleagues as having special expertise in the area of CT to make systematic inquiry into the current state of CT and CT assessment. The strength of this method is that it is not a voting or tabulating process, but a process of reaching consensus. Since a clear conceptualization of CT is absolutely essential for the development of CT instructional programs and CT assessment tools, the panel concentrated on this task.

With two caveats, for the cognitive skills dimension the panel reached consensus on six core CT skills. The caveats are that top proficiency in all skills is not a prerequisite for acquiring critical thinking ability, and these skills do not comprise a discrete "subject" to be learned in isolation, but rather are a set of purposeful skills that transcend all areas of life and learning (Facione, 1990e). Virtually unanimous consensus was shown for the skills of analysis, evaluation, and inference. Reservations were expressed by assessment experts on the panel about interpretation due to the difficulty in
distinguishing interpretation from basic communication skills, and self-regulation (Facione). Self-regulation requires one to use CT skills to evaluate one's own critical thinking. Thus, this meta-cognition has a cyclical characteristic and is difficult to assess (Facione). However, a remarkably strong consensus was reached regarding the six core skills as well as the description of their sub-skills. Facione summarized as follows:

1. Interpretation
   * Categorization
   * Decoding Significance
   * Clarifying Meaning

2. Analysis
   * Examining Ideas
   * Identifying Arguments
   * Analyzing Arguments

3. Evaluation
   * Assessing Claims
   * Assessing Arguments

4. Inference
   * Querying Evidence
   * Conjecturing Alternatives
   * Drawing Conclusions

5. Explanations
   * Stating Results
   * Justifying Procedures
   * Presenting Arguments
6. Self-Regulation
   * Self-examination
   * Self-correction (p. 12)

However, as Walsh and Paul (1986) noted, "Simply mastering a set of discrete thinking skills (recognizing assumptions or drawing conclusions, for example) does not a critical thinker make" (p. 8). This mastery of micro-skills is critical thinking in the "weak sense" (Walsh & Paul, p. 8). "CT in the 'strong sense' is when both the skills and dispositions are integrated and intrinsic ultimately to the character of a person" (Walsh & Paul, p. 8). Tishman, Jay, and Perkins (1993) strongly support the need for critical thinking dispositions. "Just as having the ability to play the piano does not guarantee the disposition to do so, having certain thinking skills does not mean one will use them" (Tishman, Jay, & Perkins, p. 149).

A majority of the panel of experts referred to previously also agreed that of necessity there is as well as a cognitive dimension, an affective dimension to CT (Facione, 1990e). This is what philosopher Harvey Siegal called the "critical spirit" — certain attitudes, dispositions (natural tendencies), habits, and character traits that entail a real commitment to using CT skills (Walsh & Paul, 1986, p.1). And while 30 percent of the panel adamantly felt these affective dispositions, while
important, should not be included in the definition of CT, the majority agreed that CT should be defined in the strong sense (Facione, 1990e). Thus, in addition to possessing CT skills, the good critical thinker should be characterized by certain affective dispositions, summarized by Facione as follows:

APPROACHES TO LIFE AND LIVING IN GENERAL:

* inquisitiveness with regard to a wide range of issues,
* concern to become and remain generally well-informed,
* alertness to opportunities to use CT,
* trust in the processes of reasoned inquiry,
* self-confidence in one's own ability to reason;
* open-mindedness regarding divergent world views,
* flexibility in considering alternatives and opinions,
* understanding of the opinions of other people,
* fair-mindedness in appraising reasoning,
* honesty in facing one's own biases, prejudices, stereotypes, egocentric or sociocentric tendencies,
* prudence in suspending, making or altering judgements,
* willingness to reconsider and revise views where honest reflection suggests that change is warranted.

APPROACHES TO SPECIFIC ISSUES, QUESTIONS OR PROBLEMS:

* clarity in stating the questions or concern,
* orderliness in working with complexity,
* diligence in seeking relevant information,
* reasonableness in selecting and applying criteria,
* care in focusing attention on the concern at hand,
* persistence though difficulties are encountered,
* precision to the degree permitted by subject and circumstances. (p. 25)

It is interesting to note that this list corresponds closely to the less descriptive list identified by D'Angelo (cited in Walsh & Paul, 1986, p. 9):

1. Intellectual curiosity
2. Objectivity
3. Open-mindedness
4. Flexibility
5. Intellectual skepticism
6. Intellectual honesty
7. Being systematic
8. Persistence
9. Decisiveness
10. Respect for other viewpoints

The panel's lists of cognitive skills and dispositions pertinent to characterizing CT also correspond closely to those described by Ennis (1985).

Thus, a key result of the panel's inquiry is a conceptualization of CT in terms of two dimensions: cognitive skills and affective dispositions summarized as follows (Facione, 1990e):

We understand critical thinking to be purposeful, self-regulatory judgment which results in interpretation, analysis, evaluation, and inference, as well as explanation of the evidential, conceptual, methodological, criteriological, or contextual considerations upon which that judgment is based. ...The ideal critical thinker is habitually inquisitive, well-informed, trustful of reason, open-minded, flexible, fair-minded in evaluation, honest in facing personal biases, prudent in making judgments, willing to reconsider, clear about issues, orderly in complex matters, diligent in seeking relevant information, reasonable in the selection of criteria, focused in inquiry, and persistent in seeking results which are as precise as the subject and the circumstances of inquiry permit. (p.3)

Ennis (1993) operating from a similar set of assumptions to those of the panel of experts cited previously offered a broadened version of his earlier definition of critical thinking. "Critical thinking is reflective and reasonable thinking that is focused on
deciding what to believe or do" (Ennis, p. 180).

Lipman (1988) considered Ennis' definition too vague because it doesn't emphasize CT in the strong sense - it doesn't include the self-correcting aspect of CT. Lipman stated that a definition of CT should include using good judgment when making a decision. Lipman emphasized the "cognitive accountability" of CT - the use of meta-criteria to assure that a decision is made rationally (p. 40). These meta-criteria include reliability, relevance, and consistency, as well as the domains of epistemology (truth and falsity are the relevant criteria) and ethics (right and wrong are relevant) (Lipman). Lipman offered this definition of CT. "I will argue that critical thinking is skillful, responsible thinking that facilitates good judgment because it (1) relies upon criteria, (2) is self-correcting, and (3) is sensitive to context" (p. 39).

Glaser (cited in Walsh & Paul, 1986) stated three principal elements of CT:

1) an attitude of being disposed to consider in a thoughtful, perceptive manner the problems and subjects that come within one's range of experiences, 2) knowledge of the methods of logical inquiry and reasoning, and 3) skill in applying those methods. (p.1)

Cornbleth (cited in Walsh & Paul, 1986) built on Dewey's description of reflective thought as "active,
persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusions to which it tends", thus identifying the essence of CT as informed skepticism (p. 8). Cornbleth stated that CT is an active inquiry rather than a passive acceptance of tradition or authority. CT is not narrowly limited to the evaluation of statements or arguments, but involves question raising, seeking information, reasoning, evaluating options, reflecting on ones thinking, and raising and pursuing further questions (Cornbleth). CT in the strongest sense is an umbrella concept. Critical thinking skills underlie, overlap, and complement all thought processes beyond memory (Walsh & Paul, 1986). This evolutionary development of what critical thinking is is summarized by Fogarty and McTighe (1993) using a quotation by Oliver Wendall Holmes about three-story intellects. They state that a maturation process has included three phases of development. Phase I was classifying a set of thinking skills, Phase II focused on the process of thinking (problem solving and invention), and currently Phase III is focusing on the thoughtful, life-long applications of transferable CT skills. CT adds the necessary evaluation process to the new ideas generated from a creative thinking process, encompasses the logical procedural steps toward solutions incorporated in problem solving theory, and utilizes the verification processes and
rational analysis of the scientific method (Walsh & Paul).

This paper proposes the following definition of CT. This definition includes the concepts that CT is driven affectively by an attitude of being disposed to open-minded questioning and critical reflection and involves acquiring and using an appropriate set of cognitive skills. This definition also includes the pragmatic side that Ennis (1985) supported. It includes the idea that the results of CT must be translated into actions. It also incorporates Lipman's (1988) argument that CT must be done with cognitive accountability which results in not just any action, but in rational action. And by including the reflective appraisal of beliefs it includes the idea of informed skepticism expressed by Cornbleth (1986). The following definition is proposed:

Critical thinking is a continual process that starts with the disposition to open-mindedly interpret, analyze, and evaluate information, ideas, arguments, solutions, or beliefs, using an appropriate set of cognitive skills that leads to a reflective appraisal/change of beliefs and results in actions.

Assessing Critical Thinking

If the goal of education is to have learners develop critical thinking skills, and changes in instructional
methodology and curriculum are required, and related social, political, and budgetary decisions are to be made, then it is necessary to be able to reliably evaluate critical thinking skills. CT is about how students think rather than just the factual answers they produce, so CT assessment must focus on how students reason, not on what information they have learned (Facione, 1989; Ruggiero, 1988). Facione stated that the heart of CT is process not product, and the research shows widely used standardized tests are not sensitive to variations in the process of using cognitive skills. Marzano and Costa (1988) looked at 6,942 items from the Stanford Achievement batteries and the California Test of Basic Skills (CTBS). They found that the test items included only 9 out of 22 general cognitive (process) skills, and more importantly, that these cognitive operations accounted for less than 3 percent of the variance on student achievement on the Stanford batteries and 4 percent on the CTBS (Marzano & Costa). However, standardized tests that do focus on the theoretical concepts of CT can measure CT skills (Facione; Ruggiero). Yet, even though a consensus on the theoretical concept of CT exists, there is agreement that there is a paucity of choice in commercially available CT tests, that most of those available are in multiple-choice format, and most test for critical thinking in the context of general knowledge rather than being subject-specific (Ruggiero; Facione; Norris,

Ruggiero (1988) listed ten commercial tests with brief summaries. Facione (1989) gave a list from the *Ninth Mental Measurements Yearbook* including reference numbers. Norris (1989) listed eight commercially available tests based on general knowledge that are comprehensive (testing a range of CT skills rather than being aspect-specific). However, in his review of 24 tests Stewart (1979) concluded many commercial tests are not based on a clearly stated theoretical concept, lack reliability and validity data, or are applicable only in narrow contexts. Even though Stewart gave the long standing and highly regarded Watson-Glaser Critical Thinking Appraisal a generally favorable review, he does find weaknesses within this fairly highly rated test.

Norris (1989) favored the general knowledge approach for testing CT skills because learners are not penalized for lacking specific facts from school subjects. Norris also favored the general approach because an ideal educational goal is that CT skills will transfer as much as possible from a somewhat sterile learning/testing environment to applications in people's everyday lives.

Facione (1989) maintained the multiple-choice format for testing CT, if constructed carefully, can overcome the problems of content and construct validity. Facione noted that Norris' use of checking pilot test items a posteriori
by direct interviews with students as they answer the questions enhances the determination of construct validity. Facione also argued that alternative forms of testing such as constructed response tests do not necessarily overcome the bias of differences in background information or cultural presumptions. Also in assessing such written responses there are the "notorious difficulties of separating specific skills being tested, test reliability, the imprecision of test results, and the impracticality of labor intensive essay testing" (Facione, p. 15). Facione (1990b) reported on research done on the multiple-choice format of The California Critical Thinking Skills Test: College Level (CCTST). The CCTST is based on the consensus conceptualization of CT which was the result of the Delphi project described previously. Results in terms of construct validity are positive (Facione, 1990b). Other reports focus on factors such as instructor performance, and student self-esteem, gender, and ethnicity, and on correlations of growth of CT skills to GPA, SAT scores, reading scores, and other measures (Facione, 1990a; 1990c; 1990d). Overall the CCTST appears to have potential as an instrument for detecting the growth of CT skills hypothesized to occur during college level instruction designed for the purpose of developing CT skills (Facione, 1993).

There is a consensus that combination testing is the best approach (Facione, 1989; Norris, 1989; Ruggiero, 1988).
Facione listed sources to support the statement that multiple-choice tests can be an efficient and practical way of gathering reliable evidence from large numbers of persons from which one might draw inferences about some of those persons' cognitive CT skills. However, multiple-choice tests "are not useful for providing information on students' dispositions to think critically" (Norris, 1989, p.30).

Norris (1989) suggested that given the importance of this dimension to the concept of CT, and the difficulty of evaluating such dispositions with pencil and paper tests, it is necessary to look for alternative approaches. Norris suggested the use of instructor and/or student journals. Norris defended making valid educational conclusions from this less quantitative data as reflecting meaning drawn from "the experienced eye" (p. 37). Norris concluded that "the informed judgement of the trained practitioner based upon records kept over a period of time certainly can lead to valid educational conclusions" (p. 37).

Thus the conclusion is that it is necessary to assess both the cognitive dimension of CT skills (which can be done successfully with a multiple-choice format) and the affective dimension of CT (which needs to be done in an alternative format to pencil and paper tests). This suggests that combination testing is the best approach. As Norris (1989) stated:

Evaluations of critical thinking are usually artificial in comparison to the life situations in
which we hope students will eventually be able and disposed to think critically. Therefore, we must keep in mind that we are trying to generalize from some more-or-less artificial evaluation situation to some more-or-less real-life situation. Such generalizations always contain some error. One way to reduce the error is to use a variety of tasks in evaluating students' critical thinking. (p. 41)

Facilitating the Growth of Critical Thinking Skills

As has been suggested already, students are not being taught to think critically (Goodlad, 1983a; Joyce, 1985; Paul, 1984; Sadler & Whimbey, 1985; Walsh & Paul, 1986). In his large study of 1,016 classrooms, Goodlad (1983a) described the data as showing an unwavering pervasiveness of instructional activity that favored passive learning. "Teachers appear to teach within a very limited repertoire of pedagogical alternatives emphasizing teacher talk and the monitoring of seatwork" and less than one percent of this teacher talk is intended to elicit student response on a higher level beyond memorization and recall (Goodlad, 1983a, p. 467). The data showed teachers "out-talking" their entire classes of students by a ratio of three to one (Goodlad, p. 467). Elaborating on the herd of sheep patterns of public education which encourages conformity, the quest for the right answers (in the back of books), and docility (take no risks), Walsh and Paul stated:

When the system overemphasizes content coverage, performance on standardized tests which primarily measure the lower order thinking skills of recall
and rote and unquestioning acceptance and docility in students, then that is what the schools will continue to produce. (p. 10)

Describing these students who have developed formulas for surviving schooling—memorizing facts for tests and manipulation, as resenting and unable to handle assignments that call on them to think independently about issues, Paul (1984) said, "They are intellectually confused and psychologically insecure, ideologically blind and philosophically indifferent" (p. 5).

There is also agreement that why teachers do not encourage students to think critically is because they themselves have not been taught CT skills, nor have they seen teaching such skills modelled in their classrooms (Goodlad, 1983a; Ruggiero, 1988; Thomas & Taylor, 1975; Walsh & Paul, 1986). Goodlad said that while teacher education espouses the ideal of immersing the neophyte in the state of the art and separating him/her from conventional practice, just the opposite occurs - "teachers teach as they were taught" (p. 469). Ruggiero described this way of teaching as rooted directly in the word "professor" coming from a Latin verb meaning not to guide or coach, but to profess—i.e. telling students what to think, not demanding that they practice thinking (p. 5).

In their comprehensive monograph Walsh and Paul (1986) described present teacher education programs as follows:

Our institutions of higher education simply perpetuate traditional approaches of elementary and secondary
education: lecture, memorization and recall. At the present time, there is little or no emphasis on critical thinking in most teacher education programs and no integration of the concepts, dispositions, or skills into education courses. Lecture continues to be the predominant teaching mode. (p. 4)

Another assertion is that if CT skills are not taught they will not occur automatically as a result of being in classes (Facione, 1990b; Ruggiero, 1988). Nor will CT skills develop naturally as a result of maturation (Ruggiero; Walsh & Paul, 1986). Studies show "the mean scores of college freshmen are less than one point above the mean scores of sixth graders on the New Jersey Test of Reasoning Skills" (Walsh & Paul, 1986, p. 5). So the need to teach CT skills is apparent. But this effort must be implemented with care to avoid the historical fate of other reforms which became fads. "The history of education reform has often seemed to be a tale of vessels laden with lofty goals being scuttled by the means used to attain them" (Sternberg, 1985, p. 194).

There is support for the following assertions. CT skills should not be taught as enrichment in basic subjects or as a separate subject divorced from the rest of the curriculum (Bereiter, 1984; Facione, 1989, 1990e; Joyce, 1985; Ruggiero, 1988; Walsh & Paul, 1986). Facione (1990e) said, "Either to transform CT into one subject field among others, or to narrow the range of CT applications strictly to domain specific subject content, would be to truncate its utility, misapprehend its nature and diminish its value" (p.
29). Joyce decried the wrangles between the emphasis on basic school subjects and the direct teaching of thinking by saying its time to "put away this childish toy of dichotomous thinking" (p. 5). "The skills of reading, the study of values, the analytic tools of scholars, and the nurture of intuition are compatible, and we can and should teach them together" (Joyce, p. 6).

Both Bereiter (1984) and Joyce (1985) stressed that teaching CT skills as enrichment or teaching CT as subject matter most likely will lead to failure. As enrichment CT skills are seen as something that can optionally be added on, and will have a low priority and easily be ignored (Joyce). Perhaps worse, it says it's all right to teach core subjects in an intellectually undemanding fashion so long as thinking is stimulated elsewhere (Joyce).

One of the problems with teaching CT as a subject is what Facione (1989) called the issue of jargon. A person can have good CT skills and not be able to identify by term what skills she/he is using, just as an artist can paint beautifully without being able to describe how the work came about (Facione, 1989). Learning CT terminology does not a critical thinker make, because CT skills need to be practiced in as many domains as possible. How useful is memorizing "evaluation of the adequacy of a conclusion" (Thomas & Taylor, 1975, p. 19)? This approach puts "students on a remote, academic mountain, thus requiring
great leaps across the intervening chasm if the rules of logic are to be applied to common life experiences" (Thomas & Taylor, p. 18). The goal of CT instruction is to give students skills that transfer out of the educational setting to everyday situations, and the best assurance this occurs is to use a permeation strategy where CT skills are a part of every aspect of an instructional program (Bereiter, 1984). Other compelling justifications for the permeation strategy are that incorporating CT into a course increases students' enthusiasm (Ruggiero, 1988) and research supports the claim that teaching CT skills increases academic achievement (Joyce, 1985; Sadler & Whimbey, 1985).

To facilitate the growth of critical thinking skills three elements are emphasized. One is the necessity of creating a nurturing instructional climate—what Lipman (cited in Walsh & Paul, 1986, p. 1) called "communities of inquiry" (Costa, 1985; Goodlad, 1983b; Sadler & Whimbey, 1985; Walsh & Paul, 1986). The second element is that instructors themselves must model CT thinking skills (Costa, 1984, Facione, 1990e; Ruggiero, 1988; Walsh & Paul). Costa (1984) said modelling is "of all the instructional techniques suggested, the one with the probability of greatest influence" on student behavior (p. 62). Citing several studies on the strong effect of modelling, Walsh and Paul suggested that educators "use this power to transform their classrooms into true communities of inquiry" (p. 11).
The third element is an emphasis on active learning - "a classroom ethos in which students are responsible not only for their own learning but also for that of their classmates" (Goodlad, 1983b, p. 558). Mentioned consistently in conjunction with this empowering of students is the use of small groups (Costa, 1985; Sadler & Whimbey, 1985; Sternberg, 1985; Thomas & Taylor, 1975).

From a practical perspective everyday life involves being able to function successfully in groups especially in the workplace, but also within the family unit and during leisure activities (Sternberg, 1985). But Costa (1984) gave an important educational justification. Costa cited studies that showed that successful critical thinkers have strong metacognitive abilities - they know what they know and don't know, can plan a strategy, are conscious of the steps taken, and can reflect on and evaluate their thinking. One way students develop these metacognitive abilities is by paraphrasing and reflecting back each other's ideas (Costa).

Of course, the latter elements are superseded by the first element because creating a learning climate where CT skills can grow is a basic requirement. "Climate" is a term that is hard to define as an operational concept. For research purposes, Korhonen and McCall (1986) and J. Davenport and J. H. Davenport (1985) used a narrow structural dimension, communication patterns, to define a learning environment. J. Davenport and J. H. Davenport
distinguished between a one-way communication pattern (from instructor to learners) and a transactional communication pattern (mutual transfers of information).

British educators Torbe and Medway (1981) presented a more descriptive visual approach:

If you go into a school or someone else's classroom, what you notice isn't the educational theory of the teacher, or the rigor of the curriculum. You see people, doing things and behaving in particular ways. ...You also notice how the teacher and the learners behave towards each other...certainly, a learning climate needs first to be a living climate--because living and learning are not distinct activities. It is the product of the countless specific actions of teachers and students, and not something achieved by legislation. (p. 141)

With a perspective towards business, Deal (1986) contrasted these types of definitions, by discussing wine. One approach is the research approach of scientists who use levels of acidity or isolate chemical factors, while the other approach is that of the wine testers who use terms like "impish" or "without a hint of pretention" (Deal, p. 41). The tasters get agreement on what is a good wine (Deal). Deal suggested describing culture as "the way we do things around here" (Deal, p. 41). This is a useful approach because an educational climate is not a set of one or more discrete elements or events. What corporations call culture, and educators call climate or environment involves the complexities of human interaction governed by an intricate weave of overt and covert rules of behavior. Climate is the way things are done in a teaching/learning
setting.

The research shows that an educational climate that is conducive to the growth of CT skills is a transactional one where students are "allies in the teaching process" (Goodlad, 1983b, p. 558). Costa (1985) and Walsh and Paul (1986) gave numerous citations supporting Sternberg's (1985) claim that problem recognition and getting students to be able to ask the right questions is an imperative. "Students need to be taught not only how to solve problems, but also how to find the problems worth solving" (Sternberg, p. 196). Students need to work together on tasks that simulate common life experiences where problems are not clearly defined, where information needed to solve problems is not itemized in a neat statement, and where solutions can be messy (no right answer in the back of the book) (Sternberg). Students need to take control of the process and be given time to paraphrase and reflect with their peers, thus strengthening their metacognitive abilities (Costa, 1984). Students also need to develop a global perspective - an open-mindedness to the ideas of others and a willingness to question the origin and validity of their own beliefs and actions (Brookfield, 1988, chap. 1; Ruggiero, 1988; Walsh & Paul, 1986). This expansion of what Walsh and Paul (p. 10) called a person's "world view" involves a certain amount of risk taking - of bucking the status quo. For this type of dialogical interaction to occur the learning climate must provide a
safety net of psychological security where failure is seen as a necessary and acceptable step in the process of learning, where opposing views are encouraged, and where the worth of an individual is paramount (Costa, 1985; Ruggiero, 1988). Major aspects of this climate of inquiry have always been espoused by adult educators and are summed up by Brookfield (1988, chap. 1) as one of mutual respect and trust (respect for each individual's worth and a setting where a challenge of ones ideas/beliefs is encouraged and does not imply personal denigration), a collaborative spirit (transactional encounters where the sole responsibility for determining curricula or establishing evaluation criteria does not rest solely with the instructor or the participants), and action and reflection (a continual process of inquiry - questioning, formulating rational plans of action, challenging beliefs, and judging actions).

The Role Of Cooperative Learning

One who learns from one who is learning drinks from a running stream.

(Indian saying)

"Because it isn't as easy as it sounds" (Peters and Austin, 1985, p. 3). The cooperative learning model appears to be ideal for teaching CT skills. It is an ecological model where building an open-minded, trusting climate of social interdependence is emphasized. N. Graves and T.
Graves (1985) proposed a six step skill building process for developing a cooperative learning climate which is developmental, but not linearly disjoint. It's the continual interaction over time of these skills and their guiding principles that promote the effective cooperative environment. Joyce (1985) recommended using a combination of several models for maximum effect when teaching CT skills. Within the framework of cooperative learning are different strategies which vary in type of task structure, goal structure and reward structure (Kagan, 1985). Cooperative learning has a strong theoretical base going back to the work of Morton Deutsch around 1920 with research on specific classroom applications beginning around 1970 (Slavin, 1991). The International Association for the Study of Cooperation in Education was founded in 1979 and has sponsored three major books in the field as well as sponsoring a quarterly magazine, Cooperative Learning.

All of this, however, does nothing to minimize the educator's immense challenge of facilitating learning in a cooperative environment. To establish such a climate of inquiry summarized previously, participants must accept certain responsibilities and interact in certain ways. Learners, indolently comfortable with passively listening and memorizing, will not easily take to being challenged as proactive learners like tadpoles take to ponds. They will be at the least anxious, and more likely resistant,
resentful, or angry (Feuer & Geber, 1988; Ruggiero, 1988; Paul, 1984).

For the educator the power of cooperative learning is not easy to harness. It takes extensive training and practice, and preparation time, especially for the neophyte practitioner, can be time consuming. Foremost it requires a major change in personal perspective. No longer is an instructor the subject matter expert, up front and in control. Instructors become facilitators, resource providers, and process evaluators - skills most do not have, have not practiced, and do not feel comfortable with. And they take personal and professional risks because such an emphasis on teaching is not supported, and not likely to be rewarded in formal institutional settings - especially at the university level (Brookfield, 1988, chap. 4). However, the research shows that for learners, this micro-level reform is well worth the effort.

Cooperative learning methods are curriculum free and must incorporate five elements (D. W. Johnson and R. Johnson, 1984):

1. Learners must develop a sense of belonging and be taught the social skills necessary for collaborative effort - leadership, listening, reflecting, and conflict resolution.

2. Learners must have face-to-face interaction. If together students do not explain, argue,
formulate, and reach a consensus on results/methods the overwhelmingly positive cognitive and affective outcomes of cooperative learning will not be realized. It is the old adage. "When you teach, you learn".

3. Each participant must pull his or her own weight. Task assignments, and evaluation and feedback, both from the instructor, and other group members, must assure this individual accountability for every student.

4. Learners must process and reflect on their group's interaction. This involves asking how well are we working together, and how can we improve?

5. Learners must work toward positively interdependent goals. Students must be as concerned with the learning performances of other students as they are about their own.

The effects of cooperative learning have been extensively researched. The results of this research have been reviewed by Slavin (1990) and D. W. Johnson and R. Johnson (1989). Slavin looked at 60 studies in elementary and secondary schools with treatment and control groups studying the same objectives for at least four weeks. D. W. Johnson and R. Johnson worked over a period of 12 years on 521 studies chosen from over 1000 articles, using three
methods of meta-analysis, the voting method, the effect-size method, and the z-score method, with subjects ranging from preschoolers, to college undergraduates, to adult learners. Both reviews showed that if the elements of positive interdependence (group goals) and individual accountability are present, cooperative learning consistently promotes higher achievement. In regards to achievement, "the evidence is overwhelming that cooperation is effective for a wide range of goals, tasks, technologies, and individuals of different achievement levels, backgrounds, and personalities" (D. W. Johnson & R. Johnson, p. 170).

"Achievement effects of cooperative learning have been found to be about the same degree at all grade levels (2 - 12), in all major subjects, and in urban, rural, and suburban schools" (Slavin, 1991, p. 71). Slavin continued by saying, "Effects are equally positive for high, average, and low achievers" (p. 71).

D. W. Johnson and R. Johnson (1989, chap. 11) stressed the presence of considerable face-to-face interaction and group processing (to improve overall group functioning) as also being important for achievement gains. With the additional presence of these elements, cooperation resulted in more frequent use of high-quality reasoning strategies, more frequent transition to higher-level reasoning, and more frequent use of meta-cognitive strategies (D. W. Johnson and R. Johnson).
As importantly, both Slavin (1990; 1991) and D. W. Johnson and R. Johnson (1989) consistently found positive effects for improved interpersonal relations, higher motivation to learn (especially intrinsic motivation), higher levels of self-esteem, and enhanced multi-ethnic relationships where participants have differentiated, dynamic, and realistic views of others as opposed to static stereotypical views. Slavin (1990) stated, "Although not every study has found positive effects on every noncognitive outcome, the overall effects of cooperative learning on student self-esteem, peer support for achievement, internal locus of control, time-on-task, and liking of class and classmates, cooperativeness and other variables are positive and robust" (p. 53).

Considering the strong correlations between elements of the cooperative learning model and the models proposed as ideal by proponents of teaching CT skills, it is logical to assume that across disciplines, use of the cooperative learning model should have a positive effect on the growth of learners' CT skills. In fact Fogarty and McTighe (1993) include utilizing cooperative learning strategies as one of their guidelines for staff development in teaching thinking skills. The research supports the statement that learning under a cooperative learning model will improve the achievement of students on the subject matter being covered. If it is found that, on top of this, they get the extra
topping, the growth of their CT skills, research with college students using the cooperative learning model is well warranted.

**Summary**

A review of the literature supports the claim that there is a lack of national will to implement educational change at any macro-level, either governmental or institutional. Reduced to the micro-level (settings where teaching and learning take place) there is major support for the need for students to be taught critical thinking skills, not only for the students' well-being, but for the well-being of society as well. The consensus is that due to the lackluster programs in most colleges of education, teachers are not trained to think critically, nor are they exposed to alternatives to the passive learning format of lecture and memorization. As a result, their students also do not experience models for critical thinking and do not learn to think critically.

Although it is a thorny issue, it is possible to define critical thinking as a construct involving both a cognitive and an affective dimension, and thus it is possible to measure the growth of CT skills. A combination of quantitative and qualitative testing is recommended.

Research indicates that growth in students' critical
thinking skills does not occur as a result of maturation or exposure to college-level course work. Students must be taught CT skills. It is recommended that CT skills should not be taught as enrichment within subjects, or as a separate discipline. Rather a permeation strategy is encouraged.

There is agreement that in order for students to learn to think critically, the educational climate must change from one of passive inertia to one of proactive learning and empowered students, where questioning and controversy are encouraged, and where, in groups, students learn to listen with a global view, and reflect on their thinking processes, thus strengthening their metacognitive abilities.

The research shows that across-the-board, the effects of cooperative learning in both the cognitive and affective domains are positive and robust. When compared to implementation strategies suggested in the literature, the cooperative learning model, which is based on a solid theoretical base, appears to be a strong model for fostering the development of students' critical thinking skills. If implementing an active learning model does improve the growth of students' critical thinking skills, the case for active learning as a way to implement micro-level educational change becomes even stronger.
CHAPTER 3. METHODOLOGY

Purpose Of The Study

In the literature there exists a strong consensus on two points. First, the climate of educational settings must change from one encouraging instructor controlled passive learning to a transactional environment that encourages mutually controlled active learning. Secondly, the overall goal of any educational process should be to reinforce and improve learners' critical thinking skills. It would be a safe conjecture to say that many administrators, professors, and instructors in colleges and universities across the United States firmly and sincerely believe that their students are given ample opportunity to learn to think critically. And that these future citizens will have improved their CT skills to the extent that they will be able to utilize these skills effectively. If this is not the case, and the literature supports this assumption, then the changes recommended in the literature required to increase the ability of students to think critically involve comprehensive structural changes. Even at the micro-level, evidence to justify such efforts needs to be established. There is abundant evidence in the literature supporting the fact that active learning, particularly a carefully facilitated cooperative learning teaching model, will result
in improved mastery of subject matter. But besides achievement gains, there is strong research support showing positive effects for students' interpersonal skills, intrinsic motivation to learn, levels of self-esteem, and enhanced multi-ethnic relationships. If it can be shown that a carefully constructed active learning environment will also improve students' CT skills, this bonus would be another strong justification for making structural changes at the micro-level.

Research Questions

This study examined the effect of an active learning environment on the growth of the cognitive critical thinking skills of first year college calculus students. The study was designed around the following research questions as stated previously in Chapter 1:

1. Is it possible to implement a change at the micro-level (locations where teachers and learners are gathered) which will have a positive effect not only on learners' achievement, but on the growth of their critical thinking skills?

2. In conjunction with #1 above, is there a teaching model with a strong theoretical base that will facilitate the growth of students'
critical thinking skills (both in terms of dispositions and cognitive skills) across disciplines, ability levels, and gender?

**Hypothesis**

The following hypothesis was tested with the alpha level set at .10:

After completing one semester of first year college calculus students learning in an environment where active learning and cooperative learning activities are the norm will demonstrate a significant growth in their ability to think critically when compared to first year calculus students learning in a traditional passive learning environment.

The findings in the literature supported using a directional hypothesis. The alpha level was set at .10 because the consequences of making a Type I error would merely be support of micro-level changes that have been consistently shown in the literature to have positive effects on students for both the cognitive and affective domains. However, making a Type II error could, in a small way, unjustifiably discourage positive structural change at the micro-level, thus possibly adversely affecting students in the future.
Assumptions

Based on the review of the literature, the following assumptions were made:

1. The concept of critical thinking can be operationally defined.
2. At the college level core CT skills can be taught and learned.
3. Growth in college level students' critical thinking skills can be validly and reliably measured quantitatively.
4. Significant measurable growth in college students' critical thinking skills can not be accounted for by maturation, nor by exposure to college level academic courses.
5. Significant measurable growth in college students' critical thinking skills does not occur because they receive instruction from educators with specific characteristics such as years of teaching experience, gender, or degrees earned.

Definition of Critical Thinking

This research design used the following proposed definition of critical thinking (CT). It is largely based on the work of Facione (1990e) who used the Delphi Method
with a panel of forty-six recognized experts in the area of CT to develop a definition of CT. But it also incorporates the thinking of Ennis, Glaser, Lipman, Norris, and Paul. It includes the idea that the results of CT must be translated into rational actions. And this definition also includes the metacognitive aspect—the accountability that comes from the reflective appraisal of solutions or beliefs.

Critical Thinking:
A continual process that starts with the disposition to open-mindedly interpret, analyze, and evaluate information, ideas, arguments, solutions, or beliefs, using an appropriate set of cognitive skills, that leads to a reflective appraisal/change of beliefs, and results in actions.

Instrumentation

Subjects chosen for the research project were given Form A of The California Critical Thinking Skills Test: College Level (CCTST) as a pretest and Form B of the CCTST as a post test. Research on the CCTST has shown there is no indication of pretest sensitization on post test scores (Facione, 1993, p.14). At the Eleventh International Conference on Critical Thinking at Sonoma, California JoAnn Carter-Wells' comprehensive analysis of four tests for CT, the CCTST, Watson-Glaser, Ennis-Weir, and Cornell, was
reported to show that the CCTST is the best commercially available CT assessment instrument (Facione, 1991). The CCTST is composed of 34 multiple-choice items which target core college level critical thinking skills. These skills were identified by a national panel of experts who participated for two years in a Delphi research project aimed at achieving an expert consensus of core CT skills at the college level. The 45 minute standardized test reports six scores: an overall score on CT cognitive skills, and five subscores on analysis, evaluation, inference, deductive reasoning, and inductive reasoning.

This instrument is not discipline nor aspect specific. Research on the CCTST (Facione, 1991) reported students who completed the CCTST found the questions both challenging and interesting. The CCTST manual (Facione, 1993) offers evidence of internal consistency, reliability, construct validity, and concurrent validity. Regarding internal consistency in the test manual Facione (1993) stated:

Internal consistency reliability estimates (Kuder Richardson-20) computed separately by pretest and posttest for the 34 item instrument ranged from .68 to .70. For an instrument of this kind a KR-20 between .65 and .75 is desirable. The internal consistency of the published version of the CCTST Form A is KR-20 = .70. For Form B the KR-20 = .71. (p. 12)

Because the definition of CT proposed in this paper is based on the work of Facione's Delphi research project, and because of the high regard for the CCTST in the literature, coupled with the statistical analysis of the test, the CCTST
was chosen for this research project.

**Subjects**

The subjects chosen were students enrolled in six sections of first year college calculus at Iowa State University. As the subjects were Iowa State University (ISU) students, the research project had to have the approval of the Human Subjects Committee at ISU. (This approval is found in Appendix A). Since it is a common belief that college students' CT skills improve merely from maturation and exposure to college level course work—especially "thinking courses" such as calculus, the fact that the subjects were calculus students added another dimension to the impact of the findings.

The subjects within sections were randomly selected to the extent that they enrolled in a certain calculus section only on the basis of fitting the course into their daily schedules. However, the sections chosen for this study were sections that had been targeted for a research project in the mathematics department at Iowa State University which was using teaching methodology as an independent variable. Thus it was possible to choose a treatment group from sections where there was a carefully planned, direct effort to create an active learning environment throughout the semester. The comparison group was chosen from sections
where a traditional, passive learning environment was the norm. The scheduled class times for the experimental and comparison sections fell within an hour of each other.

Demographically the students were representative of first year calculus students at a large, state university in the Midwest. The majority were Caucasian, were in their first year of college, and were male.

Research Procedures

The research project was designed to analyze the effects of a manipulated independent variable, teaching style and the resulting classroom climate, on the dependent variable, the growth of the subjects' critical thinking skills as measured by The California Critical Thinking Skills Test: College Level.

During the first week of the semester the instructor for each of the six calculus research sections read a letter to the potential subjects. The letter told the students about the opportunity to be part of a research project while assuring them of the confidentiality of the results. The subjects were offered a small amount of extra credit, (The amount of credit was to be uniform across all sections involved in this project.), if they completed both a pre-evaluation and a post-evaluation on two different Wednesdays during the semester. Wednesdays were chosen because the
evaluations had to be done outside of scheduled class time, and Wednesday was the one day the calculus classes did not meet. Also each student was given a reminder sheet telling when and where the pre-evaluation would occur. (Appendix B shows a copy of the letter that was read to the students and Appendix C shows a copy of the student reminder sheet.)

During the second week of the semester fifty-five students from the experimental sections, and twenty-two students from the comparison sections voluntarily took the pretest. Unexpectedly one professor for a comparison section declined to offer the extra credit incentive which perhaps partially explains the lower turn-out from the comparison sections. The students used a computer scored answer sheet to record their identification number, a two-digit code (01-05) to identify the sections they were enrolled in, and the thirty-four answers to the pretest.

During the semester all subjects completed all of the educational activities required to complete one semester of college calculus. All sections followed a standard departmental syllabus. The comparison group learned in a traditional passive learning environment under educators who had agreed to be a part of the research being conducted by a member of the mathematics department. The treatment group learned the content in a carefully and consistently facilitated active learning environment that also incorporated some aspects of a cooperative learning model.
The success of this research depended on fidelity to the treatment process. As was mentioned previously, the calculus sections were chosen from sections that were included in an on-going research project in the mathematics department at Iowa State University. The purpose of this project was to analyze how an active learning model affected the methods students used to solve problems. The three experimental sections were taught by the professor running the research and his graduate student. This professor has used active learning techniques during most of his previous teaching experiences. Because the success of his design depended on fidelity to an active learning model, it was logical to expect that a consistent effort would be put forth to facilitate an active learning environment in the experimental sections. These facts helped to insure the fidelity of the experimental treatment and thus decrease some of the threat to internal validity.

Direct verification of treatment fidelity came from structured observations of actual class sessions made by the researcher. Sections of both the experimental group and the comparison group were observed on two different days at about the half-way point in the semester. The researcher devised a structured observation form. (For copies of the forms with observations recorded for each of the observed sections, refer to Appendix D.) The main difference between any active and passive learning environment is the amount of
time spent on instructor activities (passive learning) versus the amount of time spent on student activities (active learning). An analysis of the completed observation forms clearly showed a dramatic difference in the type of learning climate that existed in the experimental as opposed to the comparison sections. For the comparison sections the "Instructor" columns were replete with tally marks for each time block throughout the class sessions. The extent of passive learning went from the extreme where in one section, no student said a single word, not to one another, nor to the instructor, to a section where some interaction occurred in the form of instructor questions and student responses or vice-versa. However, the majority of the time in the comparison sections was spent with instructor talking/writing time. Much of the time was spent on traditional lecture presentations of theorems accompanied by appropriate examples of typical problems.

In the experimental sections the paucity of tally marks in any of the "Instructor" columns is notable. Also, the observation sessions clearly revealed elements of a cooperative learning model from the way students automatically formed groups of four students and began talking intently to one another before class started, to the prepared overhead slide identifying by days which groups/partners would be presenting the results of group efforts for that day. Also of interest was that the types
of instructor activities in an experimental section, while being much less, were also very different from the types of instructor activities in the comparison sections. In the experimental sections, the instructor was often handing out group materials (a section of a sliced potato in one instance) or walking among groups hard at work stopping to give input here and there. And the responses the instructor in an experimental section gave tended to be questions—not answers. At least once during each observed experimental session student representatives from each group recorded their group results on the chalkboard and a lively discussion of the various solutions followed.

Therefore, while identifying a specific type of learning climate for the treatment sections versus the comparison sections is not feasible, without equivocation it can be stated that classroom observations verified a distinct difference in the climate and level of student involvement in the learning process between the experimental sections and the comparison sections.

During the last week of the semester the subjects were reminded about the times and locations of the Wednesday post-evaluation. During that week forty-nine subjects from the experimental group and twenty subjects from the comparison group took the post test which was Form B of The California Critical Thinking Skills Test: College Level.
The subjects recorded the exact same information in the same way as they had done when they took the pretest.
CHAPTER 4. RESULTS

Group statistics were calculated for the fifty-five subjects in the experimental group and the twenty-two subjects in the comparison group who completed the pretest. The lower number of comparison subjects can be partially explained by the unexpected decision of one professor for a comparison section to not give his students the small in-class incentive that had been previously agreed upon. Group statistics for the pretest are found in Table 1.

Table 1. Group Statistics: Pretest

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experimental</td>
<td>55</td>
<td>17.8727</td>
<td>4.6510</td>
<td>.6217</td>
</tr>
<tr>
<td>Comparison</td>
<td>22</td>
<td>18.1818</td>
<td>4.4469</td>
<td>.9481</td>
</tr>
</tbody>
</table>

The norm sample mean given in the test manual for The California Critical Thinking Skills Test: College Level (CCTST) is 15.89 with standard deviation 4.47 (Facione, 1993). A comparison to the sample populations in the study indicates that the subjects were probably motivated to perform on the pretest and that it was feasible to measure the critical thinking (CT) skills of the sample populations using the CCTST.

Table 2 shows the results of a T-test for the pretest
group means. These results show that the variances for the two groups were statistically equal and that the pretest means for the experimental versus the comparison group were not significantly different.

Table 2. T-Test: Pretest Means

<table>
<thead>
<tr>
<th>Levene's Test For Equality of Variances</th>
<th>T-Test For Equality Of Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Sig.</td>
</tr>
<tr>
<td>.017</td>
<td>.898</td>
</tr>
</tbody>
</table>

The paired statistics for the pretest and the post test for the experimental group are shown in Table 3. And the paired statistics for the pretest and the post test for the comparison group is shown in Table 4.

Table 3. Paired Statistics: Experimental Group

<table>
<thead>
<tr>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Err. Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post</td>
<td>17.7347</td>
<td>49</td>
<td>4.9488</td>
</tr>
<tr>
<td>Pre</td>
<td>18.4286</td>
<td>49</td>
<td>4.4394</td>
</tr>
</tbody>
</table>

Table 4. Paired Statistics: Comparison Group

<table>
<thead>
<tr>
<th>Mean</th>
<th>N</th>
<th>Std. Deviation</th>
<th>Std. Err. Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Post</td>
<td>18.4000</td>
<td>20</td>
<td>5.2656</td>
</tr>
<tr>
<td>Pre</td>
<td>18.2000</td>
<td>20</td>
<td>4.6634</td>
</tr>
</tbody>
</table>
The planned next step in the data analysis was to test for a significant difference in the group means for the post test. An analysis of covariance was going to be run to adjust for any difference in the pretest means and thus eliminate this source of variance. However, the paired statistics data indicated that the predicted change in CT skills as measured by The CCTST, Form B, did not occur in the predicted direction.
CHAPTER 5. DISCUSSION AND CONCLUSIONS

In some respects, the results are not surprising. The sample sizes were relatively small in a statistical sense. The duration (one college semester of instruction) is a very short duration in terms of expecting to see significant growth in a variable as complex as cognitive critical thinking skills. And the subjects in the treatment group had had little previous experience with an active learning environment (the treatment variable). So it can be assumed that there was a learning curve in terms of the treatment variable itself. It is likely that maximum treatment effects were not occurring until close to the middle of the semester, thus effectively shortening the planned duration of the treatment time.

Observations of student behavior during the post test, particularly among the treatment subjects (who were there in part out of respect for their instructors) seemed to show less performance motivation. The students tended to finish quickly (within thirty minutes) as opposed to the pretest when most students took close to the full forty-five minutes allowed. This behavior could in part be the result of familiarity with the pretest, but more likely it was end of the semester fatigue. Seasoned students, aware that the results would not affect their course grade, are not as likely to be highly motivated to perform well. In fact,
research by the author of the CCTST showed a five point difference in post test mean performance when students knew their scores would affect their final course grade (Facione, 1991).

Active learning has been shown to be particularly effective with female learners. The sample populations were in a large majority male. A more balanced gender ratio within the groups, particularly the treatment group, might have resulted in findings more consistent with the predicted outcome.

Perhaps most important to note is that this research was limited to looking at change involving the growth of the subjects' cognitive CT skills. The panel of experts referred to previously also agreed that there is of necessity an affective dimension to critical thinking (Facione, 1990e). This dimension includes attitudes, dispositions, and character traits that entail perseverance and a commitment to using CT skills. This affective dimension that is an indicator of the long-term propensity to use CT skills is perhaps of more importance even than the acquisition of cognitive CT skills, although both dimensions must be present. There is an instrument available based on Facione's definition of CT that can be used to measure changes in this affective domain. An active learning environment is likely to positively affect components of this affective dimension of CT. Including measures of
growth in the affective domain of CT might well show significant findings for subjects learning in an active learning environment.

Although it was not the focus of this study, it is interesting to note that the statistical results do show that overall for these population samples, learning college level calculus did not significantly improve the subjects' CT skills—an assumption often accepted as fact.

**Limitations**

As has been previously discussed, the study does have limitations:

1. The treatment methodology, creating an active learning environment, is not an easy task for an educator. It takes formal training, experience, and a commitment in terms of willingness to make a change in personal perspective, and in terms of time and effort. A novice attempt at creating such an environment could very well not meet standards of treatment fidelity.

2. The size of the sample populations (for both the experimental and comparison groups) was small in the statistical sense.

3. Especially when considering the learning curve for subjects being initiated to an active learning
style, the duration of treatment was probably too short to expect significant change in a complex variable like CT skills.

4. The study analyzed growth in only the cognitive skills dimension of CT. The affective dimension (which is a predictor of the duration of treatment effects) should also be analyzed in future studies.

5. The sample populations were not cross-sectional samples of a college population. The gender ratio strongly favored males, and the subjects were all learning from a single content domain—college level calculus.

Future Research

The latter two points above, the gender issue, and measuring growth in CT skills in both the cognitive and affective domains, are worthy of further research. Research has shown that in courses designed to teach CT skills as a subject, the growth of female students' CT skills lags behind those of their male classmates (Facione, 1991). Research studies designed to study gender differences in acquiring critical thinking skills when students learn in an active, cooperative environment is warranted. Perhaps an active learning environment will be shown to benefit all students in terms of acquiring CT skills. Also it is the
affective domain that predicts the persistence of an individual to continue to use CT skills. Longitudinal studies where subjects have had an opportunity to become accustomed to learning actively might show that an active learning environment increases the duration of treatment effects—certainly a desirable finding. These observations all point to interesting questions for further study.

The limitations of this study do not detract from its ecological validity. It was found that it is possible to have treatment fidelity in terms of creating an active learning environment. The limitations of duration of treatment time, and small sample size, as well as sample diversity can be easily rectified in future studies. And the treatment methodology has been robustly shown to have other positive effects on student learning, so no problem exists with the ethics of future research based on the design of this study. And although significant results were not found in this study, the findings in the literature are extensive enough to suggest that repetitions of this study, with the removal of the stated limitations, and other future studies suggested above, will yield significant and positive results with ramifications for educational change at the micro-level.
Conclusions

With a review of the literature indicating a breadth of failure in the American education system— in terms of academic achievement, in terms of promoting social equity, and in terms of developing citizens who can think critically, it appears that there is justification for a call for change. A review of the literature supports the claim that there is a lack of national will to implement educational change at any macro-level, either governmental or institutional. When considering the micro-level (settings where teaching and learning take place) there is major support for the need for students to learn in an active learning environment, and for the need for students to be taught critical thinking skills, not only for the students' well-being, but for the well-being of society as well.

In order to study the growth of students' critical thinking (CT) skills, it must be possible to define CT as a construct and to reliably measure critical thinking skills quantitatively. A review of the literature reveals that a consensus definition of CT exists, as does reliable quantitative measures of CT skills based on this definition.

This study was designed to test the following hypothesis:

After completing one semester of first year college
calculus students learning in an environment where active learning and cooperative learning activities are the norm will demonstrate a significant growth in their ability to think critically when compared to first year college calculus students learning in a traditional passive learning environment.

Two groups of first year college calculus students at Iowa State University were used as subjects. For one semester an experimental group learned calculus in a consistently facilitated active learning environment while the comparison group learned the same material in a traditional passive learning environment. The change in the subjects' critical thinking skills was measured by giving the students Form A of The California Critical Thinking Skills Test: College Level (CCTST) as a pretest during the second week of the semester, and Form B of the CCTST as a post test during the last week of the semester. Perhaps due to the limitations of this study (in terms of statistical parameters), especially the short duration of treatment time, the results did not occur in the predicted direction.

However, the results do not negatively affect the ecological validity of the study. It offered a strong consensus definition of critical thinking based on findings in the literature, it used a positively reviewed instrument, The California Critical Thinking Skills Test: College Level, to measure the growth of critical thinking skills, and it
showed that it is possible to have treatment fidelity in terms of creating an active learning environment. It pointed to some questions for further study. And because the limitations of this study can easily be rectified in any future studies, it is likely that future studies of a longer duration will yield significant results. These results will perhaps be the impetus for positive educational change at the micro-level where educators and learners interact.
APPENDIX A. HUMAN SUBJECTS APPROVAL FORMS
Information for Review of Research Involving Human Subjects
Iowa State University
(Please type and use the attached instructions for completing this form)

1. Title of Project: Measuring the Growth of the Critical Thinking Skills of College Calculus Students

2. I agree to provide the proper surveillance of this project to insure that the rights and welfare of the human subjects are protected. I will report any adverse reactions to the committee. Additions to or changes in research procedures after the project has been approved will be submitted to the committee for review. I agree to request renewal of approval for any project continuing more than one year.

Cymbelene Ann-Forbes 07/06/96 Cymbelene Ann Forbes
Typed Name of Principal Investigator Date Signature of Principal Investigator
Professional Studies 7 Atanasoff
Department Campus Address
294-6506

Phone Number to Report Results

3. Signatures of other Investigators: Date Relationship to Principal Investigator

4. Principal Investigator(s) (check all that apply)
   - Faculty
   - Staff
   - Graduate Student
   - Undergraduate Student

5. Project (check all that apply)
   - Research
   - Thesis or dissertation
   - Class project
   - Independent Study (490, 590, Honors project)

6. Number of subjects (complete all that apply)
   - # Adults, non-students 140
   - ISU student
   - # minors under 14
   - # minors 14 - 17
   - other (explain)

7. Brief description of proposed research involving human subjects: (See instructions, Item 7. Use an additional page if needed.)
   Please refer to the attached sheets.

(Please do not send research, thesis, or dissertation proposals.)

8. Informed Consent:  
   - Signed informed consent will be obtained. (Attach a copy of your form.)
   - Modified informed consent will be obtained. (See instructions, item 8.)
   - Not applicable to this project.
9. **Confidentiality of Data**: Describe below the methods to be used to ensure the confidentiality of data obtained. (See instructions, item 9.)

   Please refer to the attached sheets.

10. What risks or discomfort will be part of the study? Will subjects in the research be placed at risk or incur discomfort? Describe any risks to the subjects and precautions that will be taken to minimize them. (The concept of risk goes beyond physical risk and includes risks to subjects' dignity and self-respect as well as psychological or emotional risk. See instructions, item 10.)

   There are none.

11. **CHECK ALL** of the following that apply to your research:

   - A. Medical clearance necessary before subjects can participate
   - B. Administration of substances (foods, drugs, etc.) to subjects
   - C. Physical exercise or conditioning for subjects
   - D. Samples (Blood, tissue, etc.) from subjects
   - E. Administration of infectious agents or recombinant DNA
   - F. Deception of subjects
   - G. Subjects under 14 years of age and/or □ Subjects 14 - 17 years of age
   - □ Subjects in institutions (nursing homes, prisons, etc.)
   - □ Research must be approved by another institution or agency (Attach letters of approval)

   If you checked any of the items in 11, please complete the following in the space below (include any attachments):

   - **Items A-E** Describe the procedures and note the proposed safety precautions being taken.
   - **Items D-E** The principal investigator should send a copy of this form to Environmental Health and Safety, 118 Agronomy Lab for review.
   - **Item F** Describe how subjects will be deceived; justify the deception; indicate the debriefing procedure, including the timing and information to be presented to subjects.
   - **Item G** For subjects under the age of 14, indicate how informed consent from parents or legally authorized representatives as well as from subjects will be obtained.
   - **Items H-I** Specify the agency or institution that must approve the project. If subjects in any outside agency or institution are involved, approval must be obtained prior to beginning the research, and the letter of approval should be filed.
Checklist for Attachments and Time Schedule

The following are attached (please check):

12. ☑ Letter or written statement to subjects indicating clearly:
   a) purpose of the research
   b) the use of any identifier codes (names, #s), how they will be used, and when they will be
      removed (see Item 17)
   c) an estimate of time needed for participation in the research and the place
   d) if applicable, location of the research activity
   e) how you will ensure confidentiality
   f) in a longitudinal study, note when and how you will contact subjects later
   g) participation is voluntary; nonparticipation will not affect evaluations of the subject

13. ☐ Consent form (if applicable)

14. ☐ Letter of approval for research from cooperating organizations or institutions (if applicable)

15. ☑ Data-gathering instruments

16. Anticipated dates for contact with subjects:
   First Contact  | Last Contact
   September 4, 1996 | December 11, 1996
   Month / Day / Year | Month / Day / Year

17. If applicable: anticipated date that identifiers will be removed from completed survey instruments and/or audio or visual tapes will be erased:
    May/02/1997 | Month / Day / Year

18. Signature of Departmental Executive Officer  |  Date  |  Department or Administrative Unit
    [Signature]

19. Decision of the University Human Subjects Review Committee:
    ☑ Project Approved  |  Project Not Approved  |  No Action Required
    [Signature of Committee Chairperson]  |  Date  |  Signature of Committee Chairperson

[Signature of Committee Chairperson]

E: 8/95
7. There is strong support in the literature for the following statements:

1. An overall goal of any educational process should be to reinforce and improve learners' critical thinking skills resulting in positive effects not only for the individual learners, but for society as a whole.

2. The growth of students' critical thinking skills does not occur automatically as a result of completing college course work - nor does this growth occur simply as a result of maturation.

3. In the American education system passive learning emphasizing mastery of content facts is the norm.

4. For the growth of students' critical thinking skills to occur students must learn in a classroom climate where active learning is the norm. This involves using mutually interactive methods between educator and learners, and small group activities where metacognitive skills are practiced as students paraphrase and reflect on each other's thoughts and problem solving processes.

This study is designed to examine how facilitating an active learning environment for students affects the growth of their critical thinking skills.

The subjects will be Iowa State University students who have enrolled in first semester calculus classes for the fall semester, 1996. One group of these students will be from sections where traditional passive learning is the norm. The experimental group will come from sections where a planned active learning environment will consistently be facilitated. These subjects will volunteer to take a pretest and a post-test evaluation, after being encouraged by their calculus instructors to do so. Since these students have calculus class every week day but Wednesday, an opportunity to take these evaluations will be given on the hour, 8:00 AM to 5:00 PM on two different Wednesdays. One test day will be the second Wednesday of classes, and the following test day will be the last Wednesday of classes for the fall semester, 1996.

These volunteers will take Form A (as the pretest) and Form B (as the post-test) of the California Critical Thinking Skills Test: College Level. (Copies are attached.) This test has been reported to be the best commercially available critical thinking assessment instrument. The test has 34 multiple-choice items that target five core critical thinking skills. The 45 minute standardized test reports an overall score on cognitive critical thinking skills. It is not discipline nor aspect specific and offers statistical evidence of internal consistency, reliability, construct validity, and concurrent validity.
7. continued

The subjects will be identified only by the last four digits of their social security number. There is no need to track the subjects as individuals as the study is analyzing change in group means only.

Except for the two voluntary evaluations during the semester, all subjects will do all of the educational activities required to complete one semester of college calculus, as they normally would have done given the fact that they chose to enroll in a section of first semester calculus for the fall semester, 1996. Thus, the critical thinking scores collected from the subjects will have no direct affect on them as individuals. However, if the findings are significant, it is possible this could positively impact the way students learn calculus in the future.

9. The subjects who choose to take the pretest and post-test evaluations will be identified only by the last four digits of their social security numbers. Supplying other demographic data is not obligatory. Identification codes are needed only to check that the same individuals took the pre-test and the post-test. This study is not interested in these subjects as individuals. It is designed to compare and report on the change in group means only. Once I (the researcher) have completed the statistical analysis of the group scores, the data collection forms will be destroyed.
12. Student Information

Students:

Research is being conducted to look at ways to improve the way calculus is taught and thus enhance the skills that students have when they have completed a calculus course.

If you choose to participate in this study, you will complete a 45 minute evaluation as a pre-test and a 45 minute evaluation as a post-test here in Carver Hall during an hour of your choosing from 8:00 AM to 5:00 PM on two different Wednesdays. You will be a part of a group of students from four different calculus sections.

You will identify yourself only by the last four digits of your social security number. This code will be used only to verify that the same individuals completed both the pre-test and the post-test evaluations. No individual scores will ever be reported. Your score will be used only to compute a group average. Once these group means have been statistically analyzed your test booklets and scores will be destroyed. This will occur by the end of spring semester, 1997. It will not be obligatory for you to supply any other demographic information such as your age or gender.

This study will look at any significant changes that occur in skills you have acquired over the semester, and try to find out why any positive changes occurred, with the goal of making calculus instruction better for students in the future.

Your choice to participate in this study will be greatly appreciated. Hopefully your participation will help to improve the way calculus is taught to students in the future.
APPENDIX B. STUDENT LETTER
Students:

Research is being conducted to look at ways to improve the way calculus is taught and thus enhance the skills that students have when they have completed a calculus course.

If you choose to participate in this study, you will complete a 45 minute evaluation as a pre-test and a 45 minute evaluation as a post-test here in Carver Hall during an hour of your choosing from 8:00 AM to 5:00 PM on two different Wednesdays. You will be a part of a group of students from six different calculus sections.

You will identify yourself only by the last four digits of your social security number. This code will be used only to verify that the same individuals completed both the pre-test and the post-test evaluations. No individual scores will ever be reported. Your score will be used only to compute a group average. Once these group means have been statistically analyzed your test booklets and scores will be destroyed. This will occur by the end of spring semester, 1997. It will not be obligatory for you to supply any other demographic information such as your age or gender.

This study will look at any significant changes that occur in skills you have acquired over the semester, and try to find out why any positive changes occurred, with the goal of making calculus instruction better for students in the future.

Your choice to participate in this study will be greatly appreciated. Hopefully your participation will help to improve the way calculus is taught to students in the future.
APPENDIX C. STUDENT REMINDER SHEET
Calculus 165 Students:

If you choose to participate in this study you will be a part of a group of students from 6 different calculus sections. To earn the in-class credit you must complete BOTH the pre-evaluation and the post-evaluation. Each one takes 45 minutes. Your scores will be entirely confidential and will be used only to compute a group average. Your ID and section will be used only to insure that you are given the in-class credit for completing both evaluations. The first evaluation is on Wednesday, September 4th in:

124 Carver 8:00 - 11:00 and 18 Carver 12:00 - 6:00

You must be there at the start of any hour, but you can come at any hour from 8:00 - 6:00. Please bring a #2 lead pencil with you. If you can not come at all on Wednesday, but really want in-class credit, call me (Cym Forbes) at 294-6506. If you leave a message I will return your call. Your cooperation in participating in this study is appreciated.
APPENDIX D. CLASSROOM OBSERVATION SHEETS
<table>
<thead>
<tr>
<th>MIN'S</th>
<th>INSTRUCTOR (Whole Group)</th>
<th>INSTRUCTOR (To Individual)</th>
<th>STUDENT TALK (Question/Answer)</th>
<th>STUDENT ACT. (Individual)</th>
<th>STUDENT ACT. (Partners/Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>/ Puts up &quot;warm-up&quot; on overhead (from Internet)</td>
<td>/</td>
<td>/ Discussing &quot;warm-up&quot; question (4 students/yr)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>/ Picks up each group's solution</td>
<td>/</td>
<td>/ Discussion in groups of 4 cont's.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td>/ Talks about density holding up potato</td>
<td>/ Different students volunteer to find density of potato</td>
<td>/ Student comes up to slice potato</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td>/</td>
<td>/</td>
<td>/ Groups work finding density of slice</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td>/ Wants to subdivide slice?</td>
<td>/</td>
<td>/ continue calculations on slice dens. &amp; volume</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td>/ Asks gr. Recorders to put sols on board</td>
<td>/</td>
<td>/ Each gr's Recorder puts team sol for vol. on board</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td>/ Instructor tells students to add all vols on board</td>
<td>/ Student volunteers total vol.</td>
<td>/ Groups add up vols</td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td>/ See P.2</td>
<td>/ Answers &quot;what does this about integration&quot;</td>
<td>/</td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>/ See P.2</td>
<td>/ Circulates ring each group's diagram for $10</td>
<td>/ Students get out P.9, then try to come up with integral for vol.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Experimental 05 Comparison Students Attending 19 Date 11/14/96
<table>
<thead>
<tr>
<th>MIN.5</th>
<th>COMMENTS - Descriptive Or Inferential</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>Students sit in clusters of 3 or 4. Students &quot;discuss&quot; what Internet graph says about speed/velocity &amp; position</td>
</tr>
<tr>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td>Six group &quot;managers&quot; come up and get a potato slice and a sq cm grid sheet.</td>
</tr>
<tr>
<td>20-25</td>
<td>One group wants to subdivide slice - gets permission after explaining why to instructor. Another student expresses concern about irregular widths of slice.</td>
</tr>
<tr>
<td>25-30</td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td>Instructor is measuring displaced water by potato out of beaker with syringe - Asks &quot;what about H2O in ml and vol in cm³?</td>
</tr>
<tr>
<td>35-40</td>
<td>Instructor leads discussion about why the slice approximation just fell into ± error range.</td>
</tr>
<tr>
<td>40-50</td>
<td>Instructor makes conclusion comments about rotating half about x-axis (relating) to &quot;slicing&quot; and then integrating the vol.</td>
</tr>
</tbody>
</table>

Experimental 05  Comparison  Students Attending 19  Date 11/14/96
<table>
<thead>
<tr>
<th>MIN:5</th>
<th>INSTRUCTOR (Whole Group)</th>
<th>INSTRUCTOR (To Individual)</th>
<th>STUDENT TALK (Question/Answer)</th>
<th>STUDENT ACT. (Individual)</th>
<th>STUDENT ACT. (Partners/Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>1. writes objectives on board</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>1. picks gr. 2 &amp; gr. 5 reps to go to board</td>
<td>1. circulates among gr.s makes suggestion here &amp; there</td>
<td>1. gr. 2 delg. explains her team's sol. 2. asks why not use it?</td>
<td>1. 2 students at board</td>
<td>1. groups cont. working</td>
</tr>
<tr>
<td>10-15</td>
<td>1. asks how calculator could be used</td>
<td></td>
<td>1. student explains why T/F is not needed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td>1. talks about tasks due &amp; points</td>
<td></td>
<td>1. st. talks about why solving for y is useful</td>
<td></td>
<td>1. groups get tasks sheets ready to hand in</td>
</tr>
<tr>
<td>20-25</td>
<td></td>
<td></td>
<td>1. st. again start talking &amp; working</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td></td>
<td></td>
<td>1. groups cont. discuss &amp; start recording a sol.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td>1. puts chart from task sheet on board while gr.s work</td>
<td></td>
<td></td>
<td>1. gr. work cont.s</td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td>1. sits down with one group</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>1. explains ind. &quot;sum up&quot; task list</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1. gr. work cont.s</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Experimental 05 Comparison Students Attending 20 Date 11/12/91
<table>
<thead>
<tr>
<th>MIN-S</th>
<th>Comments - Descriptive Or Inferential</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>Students sit in clusters - talk avidly - not always about math. On board instructor is writing up task due today (project write-up &amp; test re-writes). Instructor returns papers - students talk - Often hear &quot;what if&quot; and &quot;why?&quot; about #6.</td>
</tr>
<tr>
<td>5-10</td>
<td>Instructor stops at one group - &quot;Maybe try a diagram?&quot;</td>
</tr>
<tr>
<td>10-15</td>
<td>Asks - &quot;Why did you have trouble?&quot; &quot;What techniques would be helpful?&quot;</td>
</tr>
<tr>
<td>15-20</td>
<td>Instructor explains why entering #6 sol. into calculator is necessary. Gets groups going on next section of task sheet. Sheet has a few calculator exer.s and 3 &quot;make a conjecture&quot; ques.</td>
</tr>
<tr>
<td>20-25</td>
<td>Instructor circulates among gr.s - usually responds with questions - How does that relate to...&quot; Students' hands &amp; arms are going as they disc. &quot;What's happening&quot;?</td>
</tr>
<tr>
<td>25-30</td>
<td>Inst. goes from group to group.</td>
</tr>
<tr>
<td>30-35</td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>Last task: * Individual paper sum up; write as many properties of $S$ as you can - Exately 2 min. time limit! (Students get hand-out of practice exam ques.)</td>
</tr>
</tbody>
</table>

Experimental | Comparison | Students Attending | Date 11/12/98
<table>
<thead>
<tr>
<th>MIN.</th>
<th>INSTRUCTOR (Whole Group)</th>
<th>INSTRUCTOR (To Individual)</th>
<th>STUDENT TALK (Question/Answer)</th>
<th>STUDENT ACT. (Individual)</th>
<th>STUDENT ACT. (Partner/Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>/</td>
<td>Notes given on board</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>/</td>
<td>Notes cont.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td>/</td>
<td>Notes on board cont.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>16-20</td>
<td>/</td>
<td>Writes which formulas to know on board</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td>/</td>
<td>Any questions so far?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td>/</td>
<td>Notes on board and indicates a key formula</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td>/</td>
<td>Turns and talks to group about nature of lim of Riemann sums</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td>/</td>
<td>Example on board finding area under $f(x) = x^2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>/</td>
<td>2nd Example writes notes on board about choosing $c$</td>
<td>/</td>
<td>/</td>
<td></td>
</tr>
</tbody>
</table>

Experimental | Comparison 04 | Students Attending 21 | Date 11/5/96

---

1. 0-5: Notes given on board
2. 5-10: Notes cont.
3. 10-15: Notes on board cont.
4. 16-20: Writes which formulas to know on board
5. 20-25: Any questions so far?
6. 25-30: Notes on board and indicates a key formula
7. 30-35: Turns and talks to group about nature of lim of Riemann sums
8. 35-40: Example on board finding area under $f(x) = x^2$
9. 40-50: 2nd Example writes notes on board about choosing $c$. Verifies formula after by student. Student questions form used in example.
<table>
<thead>
<tr>
<th></th>
<th>Remarks</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>Starts writing on board – rule of summation. No interaction with any st. or to whole class. Notes on board: Prmt. by induction. (\ln(M) = \frac{2}{1}) (continued)</td>
<td>30</td>
</tr>
<tr>
<td>5-10</td>
<td>Notes: list of formulas.</td>
<td>10</td>
</tr>
<tr>
<td>10-15</td>
<td>Notes: list of formulas: using previously listed formulas.</td>
<td>15</td>
</tr>
<tr>
<td>15-20</td>
<td>More examples in book – extends to concept of limit. Then to area under a curve.</td>
<td>35</td>
</tr>
<tr>
<td>20-25</td>
<td>More notes on board: Instructor reads notes aloud as he writes them on board.</td>
<td>50</td>
</tr>
<tr>
<td>25-30</td>
<td>Paces class – talks briefly about Riemann sums.</td>
<td>35</td>
</tr>
<tr>
<td>30-35</td>
<td>Asks: &quot;What is width of interval?&quot; – No short response. Finishes up problem.</td>
<td>40</td>
</tr>
<tr>
<td>35-40</td>
<td>Asks: What's the answer? - No response.</td>
<td>10</td>
</tr>
<tr>
<td>40-50</td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Comparison 04: Students Attending all Date 11/5/98

Comments - Descriptive or Inferential
<table>
<thead>
<tr>
<th>MIN/S</th>
<th>INSTRUCTOR (Whole Group)</th>
<th>INSTRUCTOR (To Individual)</th>
<th>STUDENT TALK (Question/Answer)</th>
<th>STUDENT ACT. (Individual)</th>
<th>STUDENT ACT. (Partner or Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>// Any ?'s Begins #53, p.367 Works #47</td>
<td>// Asks to see #55, asks for #47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>// #47 Cont'd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td>// #49 on board (form. for height of plant after yrs)</td>
<td>// Asks for #49</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td>// Works #57 (pos. of car &amp; truck)</td>
<td>// Asks for #57</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td>// Finishes #57 starts on-board notes</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td>// On-board notes on 4.2 cont'd</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td>// Notes cont'd on up &amp; lower Riemann sums</td>
<td></td>
<td></td>
<td>Several students answer left-end # for L</td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td>// On-board notes cont. Asks Width of interval</td>
<td>// Response: [\frac{A-b}{n}] for int. width</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>// On-board notes cont. Starts example on finding area under curve</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

Experimental ___ Comparison ___ Students Attending ___ Date ___
<table>
<thead>
<tr>
<th>TIME INTERVAL</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td>Works all examples very efficiently with confidence. Starts by setting up formulas for velocity/acc. Initial time usually $\phi$.</td>
</tr>
<tr>
<td>30-35</td>
<td>Finishes notes and starts example of finding upper and lower Riemann sums</td>
</tr>
<tr>
<td>35-40</td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>Example area under $f(x) = x^2 + 2x$ from 1 to 4. Instructor catches own error on board (makes corrections throughout example).</td>
</tr>
</tbody>
</table>

Experimental: _ Comparison: 04_ Students Attending: 21_ Date: 11/7/94
<table>
<thead>
<tr>
<th>MIN'S</th>
<th>INSTRUCTOR (Whole Group)</th>
<th>INSTRUCTOR (To Individual)</th>
<th>STUDENT TALK (Question/Answer)</th>
<th>STUDENT ACT. (Individual)</th>
<th>STUDENT ACT. (Partners/Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>/ &quot;Any ?'s&quot; starts notes on board</td>
<td>/</td>
<td>/ Responds to what numerator =</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>5-10</td>
<td>/ Notes Question to class</td>
<td>/</td>
<td>/ Responds to height ques.</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>10-15</td>
<td>/ Notes on board can't</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>15-20</td>
<td>/ Question to class Notes can't</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>20-25</td>
<td>/ Notes can't Extends to a general curve</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>25-30</td>
<td>/ starts on board example</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>30-35</td>
<td>/ Example Cont'd</td>
<td>/</td>
<td>/ Student responds to next width ques.</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>35-40</td>
<td>/ Example can't on board</td>
<td>/</td>
<td>/ Acknowledges &amp; corrects error</td>
<td>/</td>
<td>/</td>
</tr>
<tr>
<td>40-40</td>
<td>/ Summarizes process Does 2 homework examples</td>
<td>/</td>
<td>/</td>
<td>/</td>
<td>/</td>
</tr>
</tbody>
</table>

Experimental — Comparison 03  Students Attending 19  Date 11/5/94
<table>
<thead>
<tr>
<th>MIN:5</th>
<th>Comments - Descriptive Or Inferential</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>Returns tests to 2 students. Announces quiz Friday. Starts notes on board - area under f(x) = x^2.</td>
</tr>
<tr>
<td>5-10</td>
<td>Talks to group about difference of over or under estimating Riemann sums. Asks: &quot;What could go in for numerator?&quot;</td>
</tr>
<tr>
<td>10-15</td>
<td>Talks briefly about increasing number of rectangles.</td>
</tr>
<tr>
<td>15-20</td>
<td>Asks: &quot;What will height for n rectangles?&quot;. Asks: &quot;What will last height be? (Answers?)&quot;. &quot;Any questions?&quot; (No response from group.)</td>
</tr>
<tr>
<td>20-25</td>
<td>Talks to group about limit of upper and lower sums being same. Asks &quot;Any questions&quot; (No group response.)</td>
</tr>
<tr>
<td>25-30</td>
<td>Suggest using simple functions - like f(x) = -2x+7. Finds area under f(x) = -2x+7 on board.</td>
</tr>
<tr>
<td>30-35</td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td>Student questions how the summation formula was simplified. (Error is found.)</td>
</tr>
<tr>
<td>40-50</td>
<td>Points out to group they can check area computation because area under f(x) = -2x+7 is really area of trapezoid. Summarizes: Find area by building rectangles and getting usable summation formula. Does 2 homework examples - stresses getting sum of rectangles into summation notation.</td>
</tr>
</tbody>
</table>

Experimental ___ Comparison ___ Students Attending ___ Date ___/___/___
<table>
<thead>
<tr>
<th>MINS</th>
<th>INSTRUCTOR (Whole Group)</th>
<th>INSTRUCTOR (To Individual)</th>
<th>STUDENT TALK (Question/Answer)</th>
<th>STUDENT ACT. (Individual)</th>
<th>STUDENT ACT. (Partners/Group)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5</td>
<td>/ Announces Quiz</td>
<td>/</td>
<td>/ Asks for #30</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>/ Cont. #30</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td>/ Does area problem using midpoint rule</td>
<td>/ Asks for exam using midpoint rule</td>
<td>Answers: &quot;Where is 1st midpoint?&quot;</td>
<td>/</td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td>/ Cont. with on board notes on S&amp;P 25</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20-25</td>
<td>/ Notes cont. reaches formula for Riemann sums</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25-30</td>
<td>/ Notes on board cont. (see 1st page)</td>
<td>/</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30-35</td>
<td>/ Does example [ \int_{-2}^{4} (x-2) , dx ]</td>
<td>/ Asks &quot;What does (-2) tell you?&quot; (see 2nd page)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35-40</td>
<td>/ Cont. S example - gets Riemann Sum</td>
<td>/ Asks 'now about using midpoint?' (see 2nd page)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>40-50</td>
<td>/ Notes on board cont. (see 2nd page)</td>
<td>/</td>
<td></td>
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Experimental Comparison 03 Students Attending 26 Date 11/7/96
<table>
<thead>
<tr>
<th>MIN:5</th>
<th>COMMENTS - Descriptive Or Inferential</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>0-5</td>
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<tr>
<td>5-10</td>
<td></td>
</tr>
<tr>
<td>10-15</td>
<td></td>
</tr>
<tr>
<td>15-20</td>
<td>Talks about how midpt problem is the way calculator computes integration</td>
</tr>
<tr>
<td>20-25</td>
<td>Asks: (&quot;Any questions so far?&quot;) Although got no response, the pause was helpful for students to &quot;catch up&quot; cognitively.</td>
</tr>
<tr>
<td>25-30</td>
<td>Uses example of fulcrum and variable force to show why $\lim_{n \to \infty} \sum_{i=1}^{n} f(x_i) \Delta x = \int_{a}^{b} f(x) , dx$ (Appeared to cognitively helpful).</td>
</tr>
<tr>
<td>30-35</td>
<td>Explains using midpoints won't change results.</td>
</tr>
<tr>
<td>35-40</td>
<td>Uses graph to interpret ans. of -6 showing it tells the difference of areas above and below curve.</td>
</tr>
<tr>
<td>40-50</td>
<td>Concludes with properties of integrals (Puts formulas on board) like $\int_{a}^{b} (f+g) , dx = \int_{a}^{b} f(x) , dx + \int_{a}^{b} g(x) , dx$</td>
</tr>
</tbody>
</table>

Experimental 03  Students Attending 20 Date 11/7/96
REFERENCES CITED


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Quality of college education questioned by literacy study. (1994, December 10). The Des Moines Register, p. 5A.


