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The effectiveness of microcomputer simulators to stimulate environmental problem-solving with community college students.

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THE EFFECTIVENESS OF MICROCOMPUTER SIMULATORS TO STIMULATE ENVIRONMENTAL PROBLEM-SOLVING WITH COMMUNITY COLLEGE STUDENTS

A Dissertation Presented

by

JOSEPH VICTOR FARYNIARZ

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Education

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DEDICATION

This dissertation is lovingly dedicated to my parents, who always placed a premium on the education of their sons. It is by their commitment, encouragement, and self-sacrifice that I gained the fortitude to achieve this goal.

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ABSTRACT

THE EFFECTIVENESS OF MICROCOMPUTER SIMULATORS
TO STIMULATE ENVIRONMENTAL PROBLEM-SOLVING
WITH COMMUNITY COLLEGE STUDENTS

MAY 1989

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This study quantitatively examined the impact of microcomputer simulations on improving environmental problem-solving ability with community college students. Two subordinate questions were also addressed: (1) if the simulators can facilitate problem-solving heuristics, will the new strategies be able to expand into tangential domains; and (2) did reading ability bias the test instruments used to assess the outcome of the treatment? The quasi-experimental design, which parallels an earlier study by Rivers & Vockell (1987), used two intact groups of community college students. The experimental group was assigned three simulator modules that addressed lake pollution analysis, wastewater quality

management, and population dynamics. The control group was used to assess possible improvement due to Hawthorne effects.

Effectiveness was evaluated by performance on two standardized tests: the Test of Integrated Process Skills (TIPS-I & II), and the Cornell Critical Thinking Test Level-Z. Statistical analyses were done with t-tests, scatter diagrams, Pearson product-moment correlation coefficients, and linear regression. The experimental group showed significant improvement in problem-solving skills ($\alpha/2 = 0.25$) after repeated exposure to microcomputer simulators, as measured by the TIPS (Experimental Group: $\overline{X}_{gain} = +3.03$, $t_{paired\text{-}sample} = +4.42$ | Control Group: $\overline{X}_{gain} = +0.2$, $t_{paired\text{-}sample} = +0.19$). Quantitative assessment for the expansion of problem-solving skills learned via simulation was inconclusive because of external influences. For instance, the Cornell Level-Z test was subject to a reading level bias with community college students.

This study revealed improvements in other problem-solving skills not measured by the TIPS. Subjective observations, discussions, and laboratory reports suggested gains in students' metacognitive ability to weigh trade-offs in an environmental decision making process.

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CHAPTER 1

INTRODUCTION

Background

It is a "Time of Assessment" for science education in this country (Yager, 1982, p. 330). The educational literature reports many national studies which examined science education since its revival in the late 1950s. *A Nation at Risk* identified five major disciplines for the community college to address: communications, mathematics, science, social science, and computer science (Gordon, 1983). Yager (1982) recommended that science instruction recognize student diversity regarding learning styles and stages of mental development. Project Synthesis called for a greater emphasis on individualized instruction (Volk, 1984). The Carnegie Commission considered the computer to be the fourth revolution in instructional technology in higher education (Luehrmann, 1982). The National Science Board (1986) made integrating technology into the liberal arts curriculum a specific goal for two-year colleges in *Undergraduate Science, Mathematics and Engineering Education.*

Environmental education has established several goals and objectives as a result of the Tbilisi Declaration and the Hammerman Study

(Volk, 1984; Volk, Hungerford & Tomera, 1984; UNESCO-UNEP, 1984; Hammerman & Voelker, 1987). Many of these goals and objectives go beyond the acquisition of declarative knowledge. Students need to understand the complexity of environmental problems and dynamic systems. Such understanding requires problem-solving skills and other higher order thinking skills (Hart, 1981; Volk, *et al.*, 1984). A major concern is that 40% of college students are not yet formal reasoners (Lawson, 1980; Schermerhorn, *et al.*, 1982; Thomas & Grouws, 1984; Perry, *et al.*, 1986; Yeany, *et al.*, 1986). Hence, the transitional operational reasoner needs to be guided through developmental thought transitions. This requires activities which encompass first-hand experiences and opportunities for problem-solving. Microcomputers can facilitate these activities that are not possible in a traditional laboratory or classroom (Rivers & Vockell, 1987).

There have been many qualitative reports about the benefits of microcomputer use in environmental education (grades 8-12). For instance, Hinze (1984) reported that a global population simulator encouraged students to become more active learners. Saltinski (1984) described how role-playing simulators allowed students to integrate the scientific, economic, and societal parameters associated with running a nuclear power plant. Prince (1985) and Walton & McLamb (1985) observed that evolution and population simulators helped students concentrate on hypothesis testing rather than the underlying mathematical models.

However, the qualitative reports need to be corroborated by quantitative studies (Schar, 1983; Reif, 1985; Kracjik, *et al.*, 1986, 1988). Rivers & Vockell (1987) carried out a quantitative study with high school biology students, during which students used a variety of software including environmental simulators. These researchers measured gains in course content, problem-solving skills, and critical thinking skills. This National Science Foundation study reported significant improvement in content mastery and problem-solving skills.

Research Problem

Would community college students benefit from environmental microcomputer simulations? Project COMPAS investigated science education at the community college level (Schermerhorn, *et al.*, 1982). They found that community colleges have to contend with a substantial number of transitional operational reasoners. More importantly, such students learn significantly better when taught within a learning cycle (Karplus) compared to expositional instruction. High school students are also transitional operational reasoners and learn better within a learning cycle (Purser & Renner, 1983; Renner, Abraham & Birnie, 1988). The difference is that older transitional operational students are more responsive to instruction due to a greater wealth of experience and a larger mental capacity (Lawson, 1985). Therefore, community college science students, who use computer simulators, should demonstrate a greater improvement than their younger counterparts. The present study examines the effectiveness of microcomputer simulators to improve environmental problem-solving skills with community college students.

Purpose

The purpose of this study is to determine whether or not environmental problem-solving skills can improve with successive exposure to microcomputer simulations at the community college level. In addition, two subordinate questions are addressed: (1) if the simulators can facilitate problem-solving heuristics, will the new strategies be able to expand into tangential domains; (2) did reading ability bias the test instruments used to assess the outcome of the treatment?

Significance of the Study

Environmental education is beyond goal setting (Disinger, 1984); it needs to evaluate teaching methods which will accomplish its goals (Hauser, 1975; Tanner, 1985). It needs to help students build conceptual models (Schermerhorn, *et al.*, 1982; Purser & Renner, 1983; Renner, Abraham & Birnie, 1988). Traditional instruction may be sufficient for teaching declarative knowledge, but it is found lacking for teaching higher order skills at the community college level (Schermerhorn, *et al.*, 1982).

The potential to develop higher order skills, with the use of microcomputer simulators in environmental education, has been described in several reports (Hinze, 1984; Bowker & Bowker, 1986; Saltinski, 1984; Prince, 1985; Walton & McLamb, 1985). One study demonstrated a significant gain in problem-solving skills with high school students

(Rivers & Vockell, 1987). The significance of the present study is threefold: (1) it provides another quantitative investigation into the impact of microcomputer simulators on developing problem-solving skills; (2) it evaluates the potential of this technology with community college science students; and (3) it examines a possible teaching strategy which could help accomplish the goals of environmental education.

CHAPTER 2

REVIEW OF THE LITERATURE

Environmental Education

History

In the United States, nature study, outdoor education, and conservation education can be traced back to the work of such visionaries as John Muir, Gifford Pinchot, and President Theodore Roosevelt. They saw the need to preserve vast tracts of land resources for future generations to enjoy and use. Unfortunately, as *Homo sapiens* began to have greater impact on the land, destruction of seemingly unlimited resources increased (Thomas, 1956). Now humans live in a time when each day another dismal story about pollution is added to history. Rachel Carson, Aldo Leopold, Robert Teal, Barry Commoner, Garrett Hardin, and many more authors contributed to raising the nation's environmental consciousness to the point of catalyzing federal legislation.

Environmental education was first coined by Breman (1964) in an address to the American Association for the Advancement of Science (Disinger, 1985). Its formative years were between 1969 and 1974 (Tanner, 1985). Ironically, with all the discussions, conferences, and

literature generated since 1970, there still does not exist an agreed upon national curriculum for environmental education K-16 or for environmental majors 13-16 (Hart, 1981; Volk, 1984; Gupta, 1982; Disinger, 1985; Tanner, 1985) The traditional antecedents (Disinger, 1985) of nature study, outdoor and conservation education were already in place. Today the many interdisciplinary branches of environmental education includes (Gupta, 1982; Tanner, 1985): environmental engineering, environmental management, environmental studies, environmental science, environmental health & safety, environmental & societal foundations, environmental activism. It was not until the Tbilisi Declaration (1978) that an international consensus about the general goals of environmental education K-16 emerged. These worldwide goals addressed the following areas (Volk, 1984; Volk, Hungerford & Tomera, 1984; UNESCO-UNEP, 1984):

- Knowledge - of environmental concepts and problems on a local, national, and global level

- Awareness - of problems and sensitivity to the issues

- Investigation/Evaluation Skills - to identify and analyze problems

- Participation - to actively respond and help find solutions to problems via responsible activism and citizenship

Since 1974, a progressive shift has occurred from goal setting to addressing the psychological and pedagogical needs of environmental education (Brady [1972] in Hauser, 1975; Tanner, 1985). The last three goals, and the objectives distilled by the Hammerman & Voelker Study

(1987) go beyond the acquisition of declarative knowledge. The desired outcome of environmental education for non-majors is an enlightened and activated citizenry. Thus, the pedagogy should be extended to include the development of higher order thinking skills. In addition, environmental education needs to guide students through developmental thought transitions. At the community college level, science students need to be brought from concrete operational to formal operational reasoning (Schermerhorn, *et al.*, 1982), from egocentric logic to principle logic (Troy & Schwaab, 1982), and from dualistic thought to self-analyzed commitment (Perry, 1970). First-hand experiences and problem-solving opportunities would be required to accomplish such development.

The ability to identify a problem does not imply knowledge or understanding (Roth, 1979) or change in attitude or level of motivation for participation. Higher order thinking skills, problem-solving skills, creativity, divergent thought, formal reasoning, reflective judgment, lateral thinking, and many more concepts have become recently recognized educational priorities (Miller, 1981; DeBono, 1984; Morgenstern & Renner, 1984; Nickerson, 1984, Paul, 1984; Aron, 1985; Donald, 1985, Duck, 1985; Ennis, 1985 & 1987; Quellmaltz, 1985 & 1987; Patterson & Smith, 1986; Scharmann, 1986; Baron, 1987; Perkins, 1987). Essentially, the same concern radiates from all of these researchers; higher education needs to bring students from the one dimensional process of dealing only with factual knowledge into working with complex concepts. In addition, students need to be able to digest conflicting information and arrive at a holistic understanding of a situation or problem.

Environmental Education at Community Colleges

Environmental education at community colleges has evolved tremendously since it was first established 19 years ago. Although the faculty arrived with traditional backgrounds in biology, geology, and chemistry, they managed to adapt. What began as a field biology or ecology course is now an interdisciplinary endeavor. Current curriculum is a product of convergent thought focusing on six key areas: fundamental ecology, ecological diversity, populations, pollutions, energy, and environmental law.

The Center for Study of Community Colleges and the ERIC Clearinghouse for Junior Colleges carried out a national review of all community college science curricula between 1977 and 1979. Edwards (1980) reported that 63% of public institutions offered an environmental science course compared to 18% of private colleges. Understanding the interrelation between science and technology with society was a priority at 72.4% of the colleges; and developing critical thinking skills was a goal at 55.2% of the colleges. Three items of particular note were reported from environmental science instructors: (1) they use a variety of instructional methods; (2) they develop 70.6% of their own lab material (compared to 38% of the average science faculty member); and (3) they wanted more media and instructional materials, 48.3% (Edwards, 1980; Schwaab, 1983).

Community colleges have responded to the Environmental Education Act (Public Law 91-516, 1970). This legislation directed colleges to establish technical programs and general environmental courses. Technical programs were set up to meet the projected job opportunities in water treatment, energy facilities, and board of health laboratories. However, technician programs were set in place without evaluating the skills required or the low employment opportunities. While some programs are successful others are withering (Cayemberb *et al.*, [1977] in Edwards, 1980).

On a national level, non-majors had access to 30% of all environmental science course offerings in the form of a "Man and His Environment" course (Edwards, 1980). The non-major course is the primary concern in this study, because such courses may be the first and only exposure of community college students to science and environmental issues. Also, non-major courses are the most pervasive, and have higher enrollments than those for majors.

Teaching higher order skills such as problem-solving and decision making requires guided development with community college students (Schermerhorn, *et al.*, 1982; Purser & Renner, 1983; Rivers & Vockell, 1987; Renner, *et al.*, 1988). A student's thinking ability cannot be quickly transformed into formal operational reasoning or into complex critical thinking (Perry, 1970; Schermerhorn, *et al.* 1982). Pedagogy for such development needs to allow students to progressively grapple with changeable situations and complex problems (Robottom, 1985). A student needs to recognize the complexity of an environmental problem or system

to be able to reach an adaptable new solution or approach (Miller, 1981). Furthermore, a student's thought process should be open-minded to understand and possibly accept another's view. Guidance should be based on developmental learning theories like those of Jean Piaget and William Perry. A match between the intellectual developmental stage of a student with an appropriate instructional design should maximize learning. The remainder of this chapter will examine how these theories affect community college students; and how microcomputers can effectively be used to facilitate their needs in environmental education.

The Community College Student

Community colleges are linked to the Jeffersonian idea that all citizens should have the right and opportunity to an education. Thus, the primary concern of government is to have an enlightened citizenry that can make intelligent decisions when voting. Because of industrialization in the U.S., three social forces shaped the growing need for education through grades 13-14 (Cohen & Brawer, 1982). Trained workers were needed to operate the nation's expanding industries. Adolescence was becoming a longer period. There was a drive for social equality. During industrialization, science became the major catalyst for rapid economic development, hence the urgent need for science education.

Community colleges, with their open door admissions policy, brought higher education to a broader segment of the population (Cohen & Brawer, 1982). Presently, the two-year college provides for 44% of all undergraduate work (Emmeluth, 1982). In comparison to other

components of higher education, the community college deals with the most heterogeneous student population.

The Community College Student Population

Planning for community colleges has centered around the student population it serves. Therefore, the variety of courses and programs is designed to accommodate any citizen with a high school diploma or who is at least twenty-one years of age. The open door policy results in greater diversity in academic ability than is found at four-year colleges. Senior institutions usually have admission requirements based on standardized norm-referenced testing. Such testing is not done at community colleges, because their mission is to serve a broader segment of society. Students are taken from many cognitive levels and transformed into successful college graduates. Like prestigious universities, community colleges have to instruct the best prepared students; however, they need to teach the least prepared as well. A significant percentage of community college students arrive with low self-esteem because of poor scholastic records and poor preparation. Besides the poorly prepared learner, community colleges accept many first-generation college students. Often this group must persevere through more problems than students with college educated parents. While living at home, these students contend daily with the dichotomy of parental status quo and the quest to apply new knowledge. They do not sense the opportunity to discuss their learning problems at home. In isolation, these potential scholars may also have difficulty learning from some faculty who are not sensitive to their instructional needs.

Community college students come from all walks of life: recent high school graduates, the late 20-30 year old worker returning to better him/herself, the middle-aged woman who has raised and educated a family and now wants her career, the career shifter, the career equalizer, the people for whom English is a second language, the retired, the senior citizen, and the disabled. Such diversity brings problems that need to be addressed, as well as cultural richness into the classroom, laboratory, and the college community as a whole.

Besides the previously mentioned intellectual, economic, and social diversity, community college students are mainly part-time, living at home, and holding a job (often full time). This results in taking courses when convenient. Frequently, student attrition is due to lack of interest, conflicting work schedules, frustration, or other problems. Because of these situations, community college students usually do not follow a predetermined course of study. The potential student population is currently shifting to more women, ethnic minorities, disabled, retirees, and poorly prepared high schools graduates (Cohen & Brawer, 1982; Parr, 1985; Graham, 1988). For a variety of reasons, all of these groups require a certain amount of remediation.

Coping with the wide range of intellectual skills is considered to be the single most difficult problem facing community college faculty (McCartan, 1983). Many research studies concur that 40% of college freshmen cannot reason at a formal level, based on standard Piagetian tasks tests (Lawson, 1980; Schermerhorn, *et al.* 1982; Thomas & Grouws,

1984; Perry, *et al.*, 1986; Yeany, *et al.*, 1986). Considering the increase in developmental course enrollments (Alfred & Lum, 1988), this percentage is higher at Mattatuck Community College (Appendix M). A significant group of students were found to be non-formal reasoners after subsequent testing was carried out in 1989 (Appendix M). An examination of how these students learn is necessary to make community college teaching more effective.

Piaget and the Community College Learner

According to Piaget's theory of intellectual development, learning takes place through a sequence of unified stages of cognition (Sanders, 1978). Intellectual growth depends upon the formation of certain mental structures. Karplus applied Piaget's theory into a learning cycle that consists of three parts (Schermerhorn, *et al.*, 1982; Renner, *et al.*, 1988): (1) assimilation (Piaget) or exploration (Karplus), (2) disequilibrium (Piaget) or self-regulation (Karplus) or concept invention (Renner, *et al.*, 1988), (3) application (Piaget and Karplus) or expansion (Purser & Renner, 1983; Renner, *et al.*, 1988). When confronted with a new problem a learner first begins to explore concretely. The information gained from the exploration leads to self-regulation with prior knowledge and the formation of a new mental model. The newly formulated model is then applied in another situation. Piaget states that self-regulation is necessary for a new mental model to develop. The repetoire of mental models already present determines if a new situation requires the learning cycle to begin again. Existing models can be utilized for a variety of new

situations. Some new experiences, however, require the learning cycle to be repeated.

A person may not enter the next stage of development until certain mental models are in place (Sanders, 1978). This has been further supported by research on the hierarchical relationships of cognitive skills (Yeany, Yap & Padilla, 1986; Yap & Yeany, 1988). A partial explanation for this progression is attributed to nervous system development and growth (*i.e.,* myelination of the corpus callosum) (Sanders, 1978; Lawson, 1985). Researchers Pascual-Leone (1969) and Berieter & Scadamalia (1978) related the use of necessary mental structures for formal reasoning to mental capacity (in Lawson, 1985). Simply stated, a larger mental capacity is needed to manipulate a number of structures concurrently; thus, formal thought should increase with age. Building a large repertoire of mental models, and the associated strategies for their construction, should help to automate and speed the thinking process (Patterson & Smith, 1986).

Yet, physical maturity does not imply formal reasoning ability. Some adults never seem to develop beyond the concrete operational stage. Piagetian tests place many college freshmen in transition between concrete operational and formal operational stages (W. Perry, 1970; Sanders, 1978; Lawson, 1980; Bass & Maddux, 1982; Schermerhorn, *et al.*, 1982; Thomas & Grouws, 1984; Donald, 1985; B. Perry, *et al.*, 1986; Yeany, *et al.*, 1986; Appendix M). The level of formal reasoning ability is somewhat dependent upon discipline. Project COMPAS (Consortium for Operating and Managing Program for the Advancement of Skills)

examined the problem of poor science performance among community college students (Schermerhorn, *et al.*, 1982). The consortium found a significant percentage of science students functioning in the transitional stage.

The following lists summarize the characteristics of the concrete operational and formal operational students (Lawson & Renner, 1975; Bass & Maddux, 1982; Schermerhorn, *et al.*, 1982).

Concrete Operational Students are able to:

- develop meaning from first-hand experiences with objects or events
- follow simple chained logic
- formulate a simple hypothesis (inductively)
- make a direct reference to familiar
- relate own viewpoints to another simply
- investigate a variable unsystematically
- make simple classification and generalizations
- arrange objects serially (largest to smallest)

Formal Operational Students are able to:

- obtain meaning via empirical theoretical models through imagination or logic, rather than through senses; does not require concrete experiences
- isolate and control variables systematically
- recognize relationships between factors and other relationships

- use hypothetico-deductive reasoning (application of concept or law to situation)
- use a combinatorial system - mental linkages between information being processed, complex chained logic, probability, and proportion

Why are so many adults not formal reasoners? What can be done to improve their abilities? Part of the explanation lies in the learner's repetoire of mental structures. If a student never had the opportunity to develop all the necessary structures, he or she will not be able to reason formally. Thus, providing cognitive nourishment is a key issue. The problem may be the method of instruction rather than the student.

Friedlander (1980) surveyed community college science instructors. This National Science Foundation Study revealed that 94% of the instructors only lectured, 29% used lecture/demonstrations, and 10% incorporated games/simulations. This indicates the majority of instructors use a teaching method that is not effective with non-formal reasoners, because traditional lectures usually discuss concepts with theoretical models. Renner, Abraham, and Birnie (1988) reported that a teacher's initial exposition of a concept does not ensure sufficient student understanding. Traditional lectures often lack concrete exploration; hence, concrete operational and transitional operational students are disadvantaged. Non-formal reasoners need to manipulate objects or stimulate the senses, to facilitate the exploration phase of a learning cycle. Without such exploration development is stifled. Furthermore, the

guided exploration should be coupled with at least concept invention or expansion for a learning cycle to be complete (Renner, *et al.*, 1988).

Generally, the more concrete operational the student, the greater the benefit from physical tinkering. However, older non-formal reasoners are more responsive to theoretical instruction due to a greater wealth of experience and a larger mental capacity (Lawson, 1985). The theory of developmental reasoning levels does not imply that a student uses the same level for rational thought in all subjects. In some disciplines a student may already use formal reasoning, while in others he or she may still be in transition.

Many researchers have used the learning cycle concept to help the concrete operational and transitional operational student develop toward formal reasoning (Sanders, 1978; Schermerhorn, *et al.*, 1982; Purser & Renner, 1983; Thomas & Grouws, 1984; Krajcik, *et al.*, 1988; Lavoie & Good, 1988; Renner, *et al.*, 1988). This transition through exploration, concept invention, and expansion requires time (Texley & Norman, 1984), especially for the transitional reasoner. The formal reasoner will not be hindered by concrete exploration, but will formulate mental structures faster than if in an entirely abstract environment. In a meta-analysis on formal reasoning and science teaching, Lawson (1985) concluded there are three factors which can hinder progress to formal reasoning: field dependence, impulsivity, and low mental capacity. Only the last cannot be overcome in a typical college course. The following recommendations should help community college faculty develop students into formal operational reasoners.

Recommendations to Improve Science Education at the Community College

1. Provide discovery/investigative inquiry opportunities for self-regulation within the learning cycle (Sanders, 1978; Costenson & Lawson, 1986; Davis & Black, 1986).

2. Provide structured inquiry for concrete operational students (Thomas & Grouws, 1984; Jones, 1986).

3. Continually integrate science process skills (identify variables, formulate hypotheses, state functional definitions, design experiments, graph and interpret data) (Yeany, Yap & Padilla, 1986).

4. Encourage divergent thinking, brainstorming, rather than settle on a single correct answer (Schermerhorn, *et al.*, 1982).

5. Provide for group discussion to investigate, to share ideas, to analyze, and to synthesize, since this puts less demand on an individual student (Shymansky & Yore, 1980).

6. Set up situations to encourage the concrete operational student to formulate and test hypotheses. This would stimulate self-regulation (Shymansky & Yore, 1980) and foster process skills (Rhyne, 1986).

7. Recognize and emphasize the needs of the concrete operational student. The formal reasoner is more adaptable, more tolerant, and able to learn more quickly given an inquiry environment (Shymansky & Yore, 1980).

8. Promote the learning cycle over traditional approaches to teaching (Schermerhorn, *et al.*,1982; Purser & Renner, 1983; Renner, *et al.*, 1988).

9. Quiz students frequently in order to accommodate reduced mental capacity (Belzer, 1977).

10. Use introductory reading to activate prior knowledge and to prepare the mind for new information and linkages (Jones, 1986).

Perry and the Community College Learner

Environmental education is interdisciplinary. It transects the traditional disciplines of science with the social issues of activism, legislation, human ethics, and economics. Because of this interplay, students have to judge between our growth based economy and environmental crises in their decision making process (Iozzi, 1978). This kind of reflective judgment (Perry, 1970) is a necessary part of environmental education. It is not, however, addressed by Piagetian theory. Piaget's stages of intellectual growth provide a framework for

developing mental models to facilitate formal reasoning about objects (B. Perry, *et al.*, 1986). Although the process is extended into the college years, it cannot be used to explain reflective judgment (Allen, 1981; Kitchener & Kitchener in B. Perry, *et al.*, 1986). The Perry scheme is relevant to environmental education, because it gives insight on how to address the important affective domains of attitude formation and decision making. This section reviews Perry's scheme with respect to community college learners.

The Perry scheme is divided into nine positions based upon levels of thought structures. Position is used rather than stage as it implies no assumption of duration, and relates more to the point of outlook (Perry, 1970). The original work dealt solely with the mental growth of a student without regard to a specific discipline. The nine positions are grouped into three main categories: dualism, relativism, and commitment. A dualistic student only wants to know the correct answer from an authority figure (*e.g.*, the instructor). Many community college students begin in this category. They want material to be polar, absolute, and authoritarian (Widick, 1977). Such students have difficulty with interpretive questions. As reflective thought progresses, students begin to accept multiple viewpoints, although they still respect those held by the authoritarian teacher. Eventually, students not only acknowledge that there exists a multiplicity of opinion, but also that all knowledge is relative. During these positions, students recognize that accepted knowledge is really that which best fits a situation. The relativism grows and stimulates reflective judgment. Finally, given still more reflective

judgment, a student begins to take hold of a particular opinion and adopt a rational commitment. If allowed enough time, students will be able to critically weigh trade-offs and formulate sound environmental decisions.

The instructional implications are similar to those mentioned by Piaget. Instructors need to realize the level of students' reflective judgment in order to further student development. Dualistic students are not going to perform well in the pluralism of a relativistic classroom, until sufficient reflective judgment has finally raised them to that position.

The Piaget and Perry theories address the learner from two different perspectives: Piaget from formal reasoning, Perry from reflective judgment. Both researchers initially studied different age groups. However, the two theories do address the need for self-regulation before growth can occur.

B. Perry, *et al* (1986) reported that the two theories were independent of each other. Both were sequential; however, a high Piaget level does not necessarily mean a high Perry level. Piagentian development focuses upon the interaction between the learner and physical objects and concepts. In contrast, Perrian development concerns the interactions between the student, and authority figures, and peers. A person could be concrete operational yet relativistic or the reverse. The two theories are applicable to environmental education. Environmental students need to learn physical and ecological concepts as a framework for decision making in a pluralisitic society.

According to Brady (1972), environmental education has three urgent needs: (1) determination of content, (2) determination of level at which concepts can be taught effectively, and (3) determination of the best instructional methods to employ (in Hauser, 1975). Content was discussed in the first section of this chapter. How the Piaget and Perry theories address the different levels and kinds of learners was the focus of the second section. The following section addresses the third need mentioned by Brady: namely, instructional methods.

Ideal individualized instruction is a match between the level of learner and appropriate instructional design. This should precipitate an effective environment to transform students into better learners. But this ideal is modified by the realities of community college classrooms and laboratories. A more realistic goal is for instructors to enrich the educational opportunities. Use of microcomputer simulators is one possible method to enrich environmental education at the community college level.

Effective Uses of Microcomputers in Environmental Education

Environmental education deals with many interrelationships. Some interrelationships can easily be understood by drawing upon life experiences. These experiences help to adapt abstract ideas into mental structures. Traditional lectures, printed materials, and other media may effectively facilitate this process in the absence of concrete exploration. For the formal reasoner and relativistic thinker, traditional materials may be sufficient (Schar, 1983). But for the many transitional operational

reasoners and dualistic thinkers at the community college the microcomputer could be the needed dimension. Students' comprehension needs to go beyond understanding static models, because the environment is a dynamic entity. The microcomputer simulator could provide the opportunity to manipulate variables, develop problem-solving skills, and refine decision making. Simulators hold the greatest promise for the integration of microcomputers into environmental education at the community college.

Instructional Design Considerations for Software

Microcomputers have been credited with reducing learning time by one-third, increasing exam scores, and affecting a positive attitude that results in more learning (Kulik, Kulik & Cohen, 1980; Belland, *et al.*, 1985; Stennet, 1985). The major obstacle, to successfully integrate microcomputers into the curriculum, is the instructional design of the software. Technology in itself is not going to solve all the pedagogical needs of the various kinds of learners, unless it is blended with appropriate instructional design and strategy (Alessi, 1984; Bell, 1985; Belland, *et al.*, 1985; Wollenberg, *et al.*, 1985; Spillman, 1986). For example, a concrete operational student will quickly become lost and frustrated in an unstructured, open-ended ecology modeling simulator. A field dependent student may have difficulty perceiving observations from a diagram, if not somehow directed to focus on specific areas (Smith, 1985). The following sections describe several major instructional design considerations for effective software.

• Courseware needs to be interactive, flexible, and adaptive to accommodate each learner (Spillman, 1986). Traditional presentations are linear, which locksteps a group of diverse students into a process that may be appropriate or too fast or too slow. Individualized methods of instruction (*e.g.*, auto-tutorial or programmed instruction) may be adequate for some concepts, but are deficient when having to deal with dynamic systems. Good software will carry out a dialogue with the learner, allowing the student to be in control of the situation. User control allows experienced students to branch ahead, and the unsure student to repeat a section without reprisal. Sometimes external pacing (instructor controlled pacing rather than total student control) can be applied to keep computer time productive and structured (Belland, *et al.*, 1985). This would make the learning process become more efficient.

• Feedback is also essential. Since adult students are very conscious of failure and want to succeed, feedback should be positive and provide diagnostic remediation (Waugh, 1985; Spillman, 1986). Computerized practice testing can effectively help students quiz themselves (Self, Self & Rahaim, 1984). Such testing can also be used to review student progress and provide assistance in needed areas (Collins & Fletcher, 1985). This would be of special benefit for the many concrete operational and field dependent students, as well as for the insecure non-science majors.

• Visual design is an important consideration. Research indicates that reading a computer monitor may be perceived differently than reading a printed page (Smith, 1985). The text should be minimized,

specific for adults, consistently formatted on the screen, and mindful of the novice user (Spillman, 1986; Ives, 1986). Menus should always be given to provide conceptual hierarchy and advanced organizers (*e.g.*, prompts and clues) (Spillman, 1986). A menu should indicate the kind of response which is acceptable. Furthermore, graphics need to be clear and without superfluous distractors (Anderson, *et al.*, 1981).

• Added features (*e.g.*, animation, color, light pens, touch screens, *et cetera*) should only be used if they can judiciously enhance good instructional design. Otherwise, they are only novel gimmicks.

• Good software packages should promote a specific cognitive skill such as problem-solving (Ives, 1986). The software needs to efficiently present, to diagnose, and to remediate learners so that they leave the computer with mastery of a newly acquired skill.

• The software selection process should address the following four questions Crovello (1984): (1) is the material appropriate for the course and level of student; (2) is it an effective use of the technology; (3) will it promote a specific cognitive skill; and (4) does it implement good instructional design? It is important for courseware be integrated into the current curriculum and teaching style rather than determine it (Schar, 1983).

High quality packages are becoming available as a result of federal legislation and funding projects by the U.S. Department of Education and the National Science Foundation. Senator Albert Gore (1984) introduced

House Resolution 4628 to establish the National Software Corporation. It provides investment capital for private companies to produce educational software. This legislation, along with the Computer Literacy Act (House Resolution 3750) and the Computer Education Assistance Act (Senate Resolution 1848), helped to increase the preparation of better software for microcomputers in education (Walworth, 1985; Wyatt, 1985).

The National Science Foundation sponsored SUMIT (Single-concept User Adaptable Microcomputer-based Instruction Technique) and Project SERAPHIM (System Engineering Respecting Acquisition, and Propagation of Heuristic Instructional Materials). SUMIT's goal (1980) was to develop twenty software packages for post-secondary general biology and ecology (Spain, 1985b). Project SERAPHIM (1981) was established to identify, to review, and to disseminate modular chemistry software for college level (Moore, Moore & Lagowski, 1983).

Research into the effectiveness of computers in education is just beginning. The U.S. Department of Education Panel on Science & Mathematics Education has identified several kinds of needed research (Reif, 1985). First, basic research is needed regarding the fundamental issues of effective computer use and the cognitive process (Reif, 1985). Several question need to be addressed. (1) How are novice misconceptions resistant to accepting expert thought? (2) How do people organize and digest information for synthesis? (3) How do people form models of a device (concept) so that later the models can be used to diagnose a malfunction? (4) How can good thought processes be fostered?

Secondly, research is needed to develop good prototypes for educational applications of computers.

Microcomputer Simulations in Environmental Education

There are several forms of computer aided instruction: drill & practice, tutorials, games, and simulators. Of these, the educational literature indicates that microcomputer simulators hold the greatest promise for environmental education (Hinze, 1984; Kosinski, 1984; Bryant *et al.*, 1985; Saltinski, 1984; Prince, 1985; Walton & McLamb, 1985; Bowker & Bowker, 1986; Rivers & Vockell, 1987). Simulators can provide insight into real situations, because they can facilitate investigations by mathematical modeling. Students have found simulators to be an interesting way to interact with dynamic ecological systems and environmental problems. However, students and teachers need to realize that simulators do not present all the various parameters present in such systems and problems (Marks, 1982) This limitation separates it from being an exact real world (Marks, 1982; Zietsman & Hewson, 1986).

Simulations allow the following possibilities:

- manipulate variables
- statistically analyze and present data
- individualize instruction due to branching
- support inquiry based learning
- magnify student ability through accession of larger data bases (Okey, 1984)
- activate learning (Hinze, 1984)

- facilitate situations and techniques that are too dangerous, too expensive, otherwise unavailable, require too much or too little time to measure manually, too noisy, usually frustrating due to complicated technique (Disinger & Fortner, 1984)
- provide opportunities for risk assessment
- encourage strategy development
- provide opportunities for roleplaying (Bowker & Bowker, 1986)
- stimulate awareness of action and consequences (Disinger & Fortner, 1984)
- interpret structural modeling (Wallick, 1982)
- teach problem-solving skills (Manion, 1985; Schar, 1983; Rivers & Vockell, 1987)
- integrate, analyze, and compare data and concepts over time (Okey, 1984; Hinze, 1984)
- develop communication skills through networking (Okey, 1984)

The key to the success of a simulator is its level of interactivity and freshness of events (Nakhleh, 1983). Marks (1982) separates simulators into three mains types: (1) replicable performance simulators that allow students to repeat behaviors in the optimal sequence (*e.g.*, lab procedures, medical diagnosis), (2) information retrieval simulators that provide access to larger data bases for more realistic models, and (3) encounter simulators that develop greater awareness of a problem or situation through role-playing. A good package can facilitate the needs of a concrete reasoner, and provide an opportunity for exploration and conceptual invention (Renner, *et al.*, 1988).

Future development of computer assisted instruction should yield more instructionally well designed courseware. There already exists the opportunity to use larger data bases from laserdiscs and compact discs, user-friendly authoring systems for instructors to design software, and more powerful microcomputers. Future students will be exposed to an interactive learning environment which may be enriched far beyond the traditional science classroom or laboratory of today. Such an environment should provide a wealth of learning experiences to build mental models and to develop formal operational reasoning. Whether or not the computer becomes an effective instructional tool depends upon three factors: the software developers' ingenuity, the quantitative educational research to evaluate the products, and the willingness of instructors to grasp the technology for appropriate areas of the curriculum.

Summary

Environmental education was formally established in the United States under Public Law 91-516 (Environmental Education Act). It is now an interdisciplinary endeavor branching into engineering, science, management, health, law, and activism. The Tbilisi Declaration set worldwide goals that addressed knowledge, awareness, investigation and evaluation skills, and participation (Volk, 1984; Volk, Hungerford & Tomera, 1984; UNESCO-UNEP, 1984). These goals, along with the objectives from the Hammerman Study (Hammerman & Voelker, 1987), necessitate developing beyond the acquisition of declarative knowledge and into the realm of higher order thinking skills.

The current focus of environmental education has shifted from goal setting to evaluating the psychology and pedagogy required (Brady [1972] in Hauser, 1975; Tanner, 1985). Students need to gain a holistic understanding of complex environmental systems and problems. To accomplish this, curriculum activities should include first-hand experiences and problem-solving opportunities.

The mission of the community college is to provide higher education to a broad segment of society. Compared to senior institutions, community college student populations are older (mean age 28 years), and more diverse both in social background and academic ability. The wide range of intellectual skills is considered to be the most difficult problem facing community college faculty (McCarten, 1983).

Many research studies concur that 40% of college freshmen cannot reason at a formal level (Lawson 1980; Schermerhorn, *et al.* 1982; Thomas & Grouws, 1984; Perry, *et al.*, 1986; Yeany, *et al.*, 1986). This percentage is higher at the community college (Schermerhorn, *et al.*, 1982) which has a substantial number of developmental students (Alfred & Lum, 1988). Recently, community colleges recognized the gap between traditional college instruction and the needs of its student population. Project COMPAS searched for a change to address the problem of poor student performance at the community college level (Schermerhorn, *et al.*, 1982). Its steering group reconsidered Piaget's developmental stages.

According to Piaget, learning takes place through a sequence of unified stages of cognition (Sanders, 1978). For college students, the stages extend from concrete operational to formal operational reasoning. Intellectual growth depends upon the formation of certain mental structures. The process was adapted into a learning cycle by Robert Karplus (Schermerhorn, *et al.*, 1982). The cycle consists of three parts: exploration, self-regulation, and application.

Schermerhorn, *et al.* (1982) reported that the more concrete operational a reasoner, the greater the need to learn by physical tinkering. Formal operational reasoners are able to learn without concrete experience; they can draw upon a larger repetoire of mental structures. Piaget's theory can be useful in those areas of environmental education which deal with objects or systems. But, another aspect of environmental education requires that students be able to grapple with laws, policies, and people.

The Perry scheme (1970) examined how thinking develops from dualism to commitment. According to Perry (1970), a student becomes progressively less dependent upon authoritarian views with increasing periods of reflective judgment. Eventually, a student acknowledges multiple viewpoints and establishes his or her own decision.

Environmental education has three urgent needs: (1) determination of content, (2) determination of level at which concepts can be taught effectively, and (3) determination of the best instructional methods to

employ (Brady, [1972] in Hauser, 1975). The present study examines one such instructional method: the microcomputer simulator.

The education literature indicates the microcomputer simulator to hold great promise for environmental education ((Hinze, 1984; Kosinski, 1984; Bryant *et al.*, 1985; Saltinski, 1984; Prince, 1985; Walton & McLamb, 1985; Bowker & Bowker, 1986; Rivers & Vockell, 1987). Through simulators students can manipulate variables. They can work with systems or problems that are too large or too complex for the traditional laboratory. Role-playing and risk assessment can also be facilitated. Marks (1982) classifies simulators into three mains types: (1) replicable performance simulators that allow students to repeat behaviors in the optimal sequence, (2) information retrieval simulators that provide access to larger data bases for more realistic models, and (3) encounter simulators that develop a greater awareness of a problem or situation through role-playing.

For courseware to be effective, it needs to be interactive, flexible, and adaptive (Spillman, 1986). It should also promote a specific cognitive skill (Ives, 1986), as well as provide diagnostic feedback. A good package can facilitate the needs of a concrete operational reasoner; it can provide an opportunity for exploration and conceptual invention (Rivers & Vockell, 1987; Renner, *et al.*, 1988).

The National Science Foundation and the U.S. Congress have established several programs to integrate computer technology into science curricula. Whether or not the computer becomes an effective

instructional tool depends upon three factors: the software developers' ingenuity, the quantitative educational research to evaluate the products, and the willingness of instructors to grasp the technology for appropriate areas of the curriculum.

CHAPTER 3

EXPERIMENTAL DESIGN

The community college student population contains a large number of non-formal reasoners. These students require concrete exploration to develop scientific problem-solving skills. They need a kind of scientific inquiry that facilitates the manipulation of variables involved in environmental problems. Some environmental investigations can easily be done in the field or laboratory (*e.g.*, level of sewage contamination via coliform count, determination of soil fertility, or wetland classification). However, many environmental investigations are too vast to bring into the laboratory (*e.g.*, river systems management). Some require mathematical formulae or models which are too complex (*e.g.*, population dynamics). Still others depend upon laboratory techniques which are too time consuming to teach (*e.g.*, chemical instrumental analysis). Total dependence upon extraperceptual experiences (*i.e.*, lectures, readings, and audiovisual materials) may not promote learning further than cognitive content.

Reports indicate that microcomputer simulators are able to stimulate the learning cycle into the higher levels of understanding:

specifically, concept invention (Renner, *et al.*, 1988) and expansion (Purser & Renner, 1983; Renner, *et al.*, 1988). As such, simulators could provide a teaching method that is superior to traditional instruction for improving environmental problem-solving skills.

The need to integrate computers into science education has been established (Nation Science Board, 1986). Many reports describe how researchers and instructors have begun to utilize the available technology. Medical (Balson, *et al.*, 1984; Pomeroy & Toothman, 1984; Branch, *et al.*, 1987), military (Gibbon, *et al.*, 1982), and corporate training programs (Bunderson, *et al.*, 1981; May, 1984; Tuscher & Harvey, 1985; Soliwoda, 1986; Spencer, 1983; Sweeter, 1986) have been leaders in research with controlled studies. Kulik, *et al.* (1980 & 1986) carried out meta-analyses of the literature involving the use of computers in college teaching. The studies reviewed indicate that students benefit from classroom computer use in several ways: (1) increased achievement, (2) reduced learning time, (3) activated student interests, (4) increased course completion, and (5) encouraged positive attitudes about computers.

There have been several concerns raised about the methodologies and assessments used in previous research. Subsequent studies should address these concerns in order to better evaluate computer use in education. Software characteristics need to be further documented (Kracjik, *et al.*, 1986). Effects from contextual variables associated with the classroom should be isolated and controlled (Collis, 1987). The testing instruments should be evaluated for content and construct validity, and for external biases (*i.e.*, computer anxiety, mathematics, and reading

levels). The U. S. Department of Education Panel on Science & Mathematics Education has identified several kinds of basic research needed for computers in education (Reif, 1985). There is a specific need for quantitative research into the effectiveness of computers in mathematics and science education.

A Parallel Study

Rivers and Vockell (1987) carried out a controlled study (sponsored by the National Science Foundation) that is relevant concerning the use of microcomputer simulators in environmental education with community college students. Ninth grade biology students, from three different kinds of communities, were exposed to seven biology simulator packages. Three standardized tests were used to determine effectiveness. The BSCS Process of Science Test, that surveys an entire high school biology curriculum, measured the improvement in subject achievement. The Test of Integrated Process Skills (TIPS) was used to determine gains in scientific problem-solving. Improvements in higher order thinking skills was assessed by the Watson-Glaser Critical Thinking Appraisal. The control group was given traditional classroom instruction in place of the computer simulators. The results indicated that the experimental group performed significantly better than the control on the simulator posttests and on the test of scientific thinking (TIPS). Performance on the critical thinking assessment (Watson-Glaser) was mixed; two schools reported a gain, while the third school reported no

gain. Rivers and Vockell quantitatively determined, therefore, that microcomputer simulations could stimulate scientific problem-solving.

Several important observations should be noted from their research. This study is one of the first to quantify the effectiveness of microcomputer use to stimulate higher order thinking. The results partially indicated that students could expand upon the problem-solving skills learned from computer software. Although Rivers & Vockell reported a significant percentile gain in critical thinking, the raw score gains were much smaller. The norms for the Watson-Glaser Critical Thinking Appraisal indicate that a small increase in raw score would yield a greater increase in percentile. However, because the Watson-Glaser uses a Likert scale of acceptability, the actual gains may have been underestimated for the ninth graders.

The Rivers & Vockell study is pertinent for environmental education with community college students. They used software that included a mixture of drill and practice, games, and simulations. Two of the simulations dealt with environmental problems. Students did improve their problem-solving skills having used the simulations. Both high school and community college student populations contain many non-formal operational reasoners.

Can the approach used in the Rivers & Vockell study be applied to the diverse community college student population? The present study parallels the research design of the Rivers & Vockell study; however, several changes were made. The data collected should produce more

specific information about the effectiveness of microcomputers in environmental education. It should also reveal if simulators are effective with this population. A general list of modifications from the Rivers & Vockell study are as follows:

1.) The study group was community college students with an age distribution between 18-73 years old (mean = 28 years).

2.) The simulators used were extensively field tested in terms of design, and target population by their authors (Project SERAPHIM, the Diversified Educational Enterprises, Inc., and the Educational Materials & Equipment Corporation).

3.) The Cornell Critical Thinking Test Level-Z replaced the Watson-Glaser Appraisal. The main reasons for this change were test item construction, content validity, and construct validity for the studied population. Only raw scores were statistically analyzed not percentiles.

4.) Testing instruments were examined for the presence of an external bias (*i.e.*, reading level).

Because the environment is a dynamic entity, students' comprehension needs to go beyond understanding static models. The microcomputer could provide the necessary opportunity to manipulate and explore otherwise impossible variables (*e.g.*, too vast, too complex). Such concrete explorations should facilitate the learning cycle and foster

problem-solving heuristics. This study is expected to demonstrate that simulators hold great potential for the integration of microcomputers into environmental education at the community college.

Research Question

Can microcomputer simulators effectively improve environmental problem-solving skills with community college students?

Overview

Two intact groups of students, a control and an experimental, were used in a quasi-experimental design. The control group was not exposed to any microcomputer simulators, while the experimental group used three environmental simulator packages. Gain scores on the Test of Integrated Process Skills (TIPS) and Cornell Critical Thinking Test Level-Z were used to measure treatment effectiveness. Nelson-Denny reading scores were compared with the pretest scores (TIPS and Cornell-Z) to determine if there existed a bias to student performance in this study.

Subjects

The source of data in this study was a finite population composed of environmental science and general biology students enrolled at Mattatuck Community College, Waterbury, Connecticut during the 1987/1988

academic year. The decision to restrict the study to these sections was made on the basis of equipment logistics, and control of teacher influences and other contextual variables.

The subjects were from intact groups based on course enrollments. The student body at Mattatuck Community College was 3500. Both environmental science and general biology courses do not have any prerequisites. These courses usually enroll a cross section of students from a variety of programs. This is due to a common core curriculum science requirement at the college.

The student sample had a median age of approximately twenty-eight years. All undergraduates have at least a high school diploma or are over 21 years old. None should have placed into any remedial courses. Student questionnaires indicated that in previous years at least 66% of the students did not have science since their sophomore year of high school, and that 75% of the student did not have prior computer experience.

Methodology

This study was set up as a quasi-experimental design to quantitatively examine the impact of microcomputer simulations on developing environmental problem-solving ability. Two subordinate questions were also addressed: (1) if the simulators can facilitate problem-solving heuristics, will the new strategies be able to expand into tangential domains; and (2) did reading ability bias the test instruments used to assess the outcome of treatment? The intact experimental group was

successively exposed to three environmental simulator modules. The intact control group was a general biology class not exposed to simulators. The purpose of the control group in the quasi-experimental design was to address improvement due to Hawthorne effects. This study was to determine improvement in problem-solving skills by the experimental group; it was not a comparative investigation (Figure 1).

A pilot study was carried out during spring and fall 1987. Its function was threefold: (1) established student interest in using computer simulators in an environmental science class, (2) field tested the simulation packages for instructional design problems, and (3) determined logistics. The formal study was done during the spring 1988 semester with one section of environmental science and one section of general biology students. Since the environmental aspects of the curriculum in both courses intersected, the students were considered to be a single population.

Baseline data on student reading level was obtained from the college admissions office. Although these scores were readily available, the researcher asked students for their release, as well as their agreement to participate in the study (Appendix A). The college uses the Nelson-Denny standardized test to assess reading level and subsequent placement into developmental course. Students with deficiencies in reading, English or mathematics are assigned to remedial courses. Such students are counselled away from science until their scores improved.

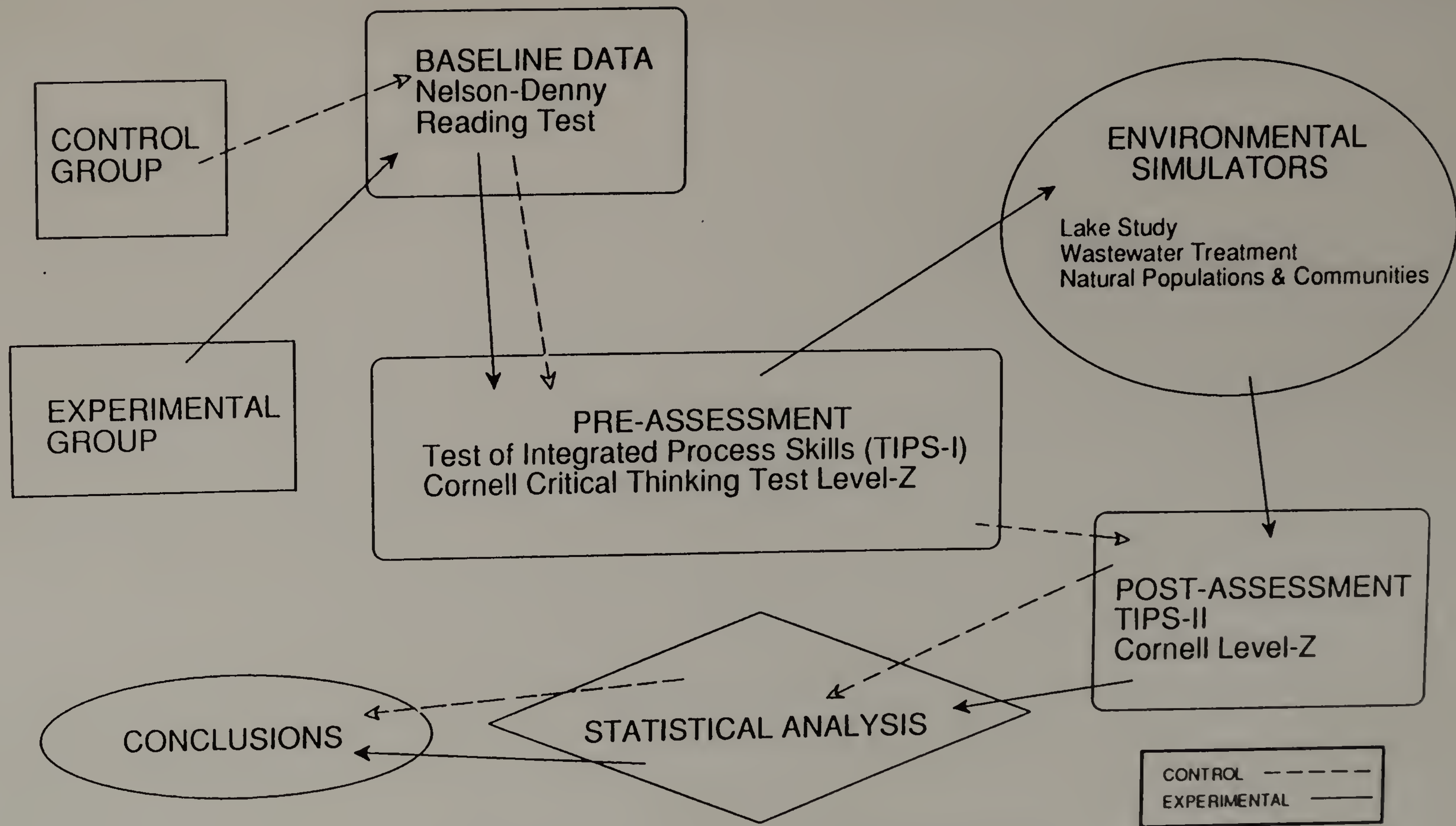


FIGURE 1. Flowchart of Experimental Design

Pre-assessment instruments were administered to establish the level of scientific process skills and critical thinking prior to simulator use. The Test of Integrated (science) Process Skills I & II, (Dillashaw & Okey, 1980; Burns, Wise & Okey, 1985) were also used in the Rivers & Vockell Study (1987). This test measured students' ability to identify variables, to operationally define variables, to identify and state hypotheses, to design investigations, and to interpret tables and graphs. Problem-solving is considered part of a larger domain; therefore, the Cornell Critical Thinking Test Form-Z (Ennis, Millman & Tomko, 1985) was used. This test measures observation statements, judging credibility, induction, deduction, and assumption identification. These constructs were thought to be appropriate for assessing the expansion of problem-solving skills in higher order thinking. The TIPS-I was used as the pretest and the TIPS-II as the posttest. The Cornell Level-Z was used for both pretest and posttest for two reasons. It did not have an alternate form. It was implemented to measure a subordinate question. Both the TIPS and Cornell Level-Z were previously normed with appropriate sample populations. All of these assessments had content validity and construct validity relevant to this study.

Microcomputer simulators were selected after an extensive review of available environmental software (Appendix K). Software evaluation criteria was based upon the instructional design considerations discussed in Chapter 2. Three guided student activity modules were written (Appendix B, C, D). Two modules utilized software from Project SERAPHIM (System Engineering Respecting Acquisition, and Propagation of Heuristic Instructional Materials). The third module used

software from Diversified Educational Enterprises, Inc. and the Educational Materials and Equipment Corporation. All of the materials had been longitudinally tested by the publishers for design, for programming quirks, and for other important software considerations. A description of the software used in each modules follows.

Aquatic Pollution Part 1 - *Lake Study* (Project Seraphim) - This simulator presented an environmental problem in which fish were dying in a hatchery. Students investigated the problem using many complex chemical and biological analysis techniques (*e.g.*, atomic absorption, spectrophotometry, gas chromatography, mass spectroscopy, and bioassay).

Aquatic Pollution Part 2 - *WAQUAL: Wastewater Quality Analysis* (Project Seraphim) - This simulator allowed students to role-play as the superintendent of a municipal wastewater treatment plant. It provided realistic parameters such as changing seasons, EPA inspectors, a town council budget, and irate citizens from a beach down-river.

Natural Populations & Community Dynamics - This module incorporated interactive tutorials and simulators. *Population Concepts & Community Dynamics* (Educational Equipment and Materials Corporation) and *Balance* (Diversified Educational Enterprises, Inc.) presented students with many factors associated with populations and communties. These factors included kinds of growth, carrying capacity, migration, type of habitat, minimum breeding density, escape rates,

hunting pressure, and predator/prey ratio. Students had to successfully manage a deer population.

Each simulator module contained a pretest/posttest, study objectives, and guided study design. Students were required to do as follows: (1) determine a statement of the problem, (2) establish hypotheses to be tested, (3) design an experiment, (4) control the variables, (5) interpret adequacy of data, (6) analyze and present data, (7) draw conclusions based upon the hypotheses and inference from data, and (8) suggest further study. The pretest/posttests (15 objective items) provided student feedback about their content mastery. To ensure validity, each module and pretest/posttest were reviewed by colleagues against the stated objectives.

Microcomputers were set up in a science laboratory and the learning resource center at another part of campus. This allowed student use both during and outside of class time. The environmental simulators were part of the normal environmental science course curriculum. Scores on the standardized test were only used for data in this study; they had no impact on final course grades.

Statistical Hypotheses

```
             KEY
                     first test                                last test
                     |  group number.....................|
                     |  |  test number...................|
Control              |  |  |.............................|
Group                F  1  2----------------------------L  1  1
                     F  1  2----------------------------L  1  2

Experimental
Group                F  2  1----------------------------L  2  1
                     F  2  2----------------------------L  2  2
```

group 1 = control
group 2 = experimental
μ = population mean

First test 1 = TIPS-I or pre-Cornell-Z
Last test 2 = TIPS-II or post-Cornell-Z
r = Pearson product-moment correlation coefficient

Statistical Hypothesis I

H_O: Student environmental problem-solving will not improve with the use of microcomputer simulators.

H_A: Student environmental problem-solving skills will improve with the opportunity to use microcomputer simulators.

Sub-hypothesis Ia

H_O: The control group is representative of the experimental group, as measured by the TIPS test.

H_A: The control group is not representative of the experimental group, as measured by the TIPS test.

$$H_O: \mu_{F11} = \mu_{F21}$$

$$H_A: \mu_{F11} \neq \mu_{F21}$$

Sub-hypothesis Ib

H_O: Scientific problem-solving skills, as measured by the TIPS, will not improve with repeated exposure to microcomputer simulations.

H_A: Scientific problem-solving skills, as measured by the TIPS, will improve with repeated exposure to microcomputer simulations.

$$H_O: \mu_{F21} = \mu_{L21}$$

$$H_A: \mu_{F21} < \mu_{L21}$$

Sub-hypothesis Ic

H_O: Gain in student performance in scientific problem-solving skills, for the experimental group is not significantly better than the performance of the control group, as measured by the TIPS.

H_A: Gain in student performance in scientific problem-solving skills for the experimental group is significantly better than the performance of the control group, as measured by the TIPS.

$$H_O: (\mu_{F11} - \mu_{L11}) = (\mu_{F21} - \mu_{L21})$$

$$H_A: (\mu_{F11} - \mu_{L11}) < (\mu_{F21} - \mu_{L21})$$

Statistical Hypothesis II

H_O: Students will not be able to expand environmental problem-solving skills mastered from a computer simulator to new applications, as measured by the correlation between the TIPS and Cornell gain scores.

H_A: Students will be able to expand environmental problem-solving skills mastered from a computer simulator to new applications, as measured by the correlation between the TIPS and Cornell gain scores.

$$H_O: r_{1(\Delta 1:\Delta 2)} = r_{2(\Delta 1:\Delta 2)}$$

$$H_A: r_{1(\Delta 1:\Delta 2)} < r_{2(\Delta 1:\Delta 2)}$$

Statistical Hypothesis III

H_O: Baseline reading level presents a bias to student performance in learning problem-solving via the microcomputer simulator.

H_A: Baseline reading level does not bias student performance in learning problem-solving via the micromputer simulator.

Sub-hypothesis IIIa

H_O: There is no correlation between problem-solving, as measured by the TIPS, and reading ability.

H_A: There is a correlation between problem-solving skills, as measured by the TIPS, and reading ability.

$$H_O: \quad r = 0$$

$$H_A: \quad r \neq 0$$

Sub-hypothesis IIIb

H_O: There is no correlation between the expansion of scientific problem-solving, a measured by the Cornell Critical Thinking Test Level-Z, and reading ability.

H_A: There is a correlation between the expansion of scientific problem-solving, as measured by the Cornell Critical Thinking Test Level-Z, and reading ability.

$$H_O: \quad r = 0$$

$$H_A: \quad r \neq 0$$

Analysis of Data

Data was analyzed by two different t-test statistics: the two-sample t-test for independent sample means, and the paired-sample t-test. A 95% level of significance was established as the critical region for hypothesis testing. Scatter diagrams and the Pearson product-moment correlation coefficients were calculated to determine the existence of any relationships between data. Linear regressions were also plotted. *Statfast* (1985) and *Basic Statistics* (1984) software were used to verify hand calculations for the t-tests and correlations. *Cricket Graph* (1988) software was used to plot the three dimentional histograms, scatter diagrams, as well as calculate and draw the regression lines.

CHAPTER 4

RESULTS

Statistical analysis of the results was done within the context of the hypotheses stated in the experimental design (Chapter III p. 43). All tables and figures referenced are located at the end of this chapter (beginning on page 62).

Hypothesis I

The null hypothesis, that student environmental problem-solving would not improve with the use of microcomputer simulations, was rejected. Three sub-hypotheses were employed to make this statistical decision. Analysis for each sub-hypothesis indicated invariably that the experimental group performed significantly better than the control group.

Sub-hypothesis Ia addressed if the control and experimental groups representative of each other based upon the Test of Integrated Process Skills (TIPS). A summary of the data and descriptive statistics for the TIPS pretest/posttest, from both the control and experimental groups, is found in Table 1 (Figures 2 & 3). The mean pretest scores for both groups were analogous (Control = 22.38, Experimental = 23.47). The F-test and t-test statistics for two independent means (Johnson, 1976)

compared the variances and sample means of the pretest scores. These tests determined if the control and experimental groups were initially representative of each other. The test statistics chosen allowed inferences to be made between two independent means when at least one sample size is small ($n \leq 30$, *e.g.*, control group) and the other large ($n > 30$, *e.g.*, experimental group). A 95% level of significance (two-tailed) was established for the test statistics with $F_{(d.f. = 23, 33;\ \alpha/2 = 2.14)}$ and $t_{(d.f. = 56;\ \alpha/2 = \pm 1.96)}$. Both the F-test and $t_{\text{two-independent means}}$ test results failed to reject the null hypothesis (F = 1.03; t = -0.17). Ergo, the control group was considered to be representative of the experimental group. It could be used for further comparisons in this study. There did exist a 5% chance of a Type I error (rejecting a true null hypothesis).

Sub-hypothesis Ib tested if exposure to simulators would improve scientific problem-solving. This investigation used a quasi-experimental design. The crucial question was, would the average gain in TIPS score be significantly greater than zero? The paired-sample t-test statistic compared the gain scores of the experimental group on the TIPS (Table 1). This test statistic was more sensitive to the individual differences between related pairs of data (*e.g.*, pretest vs. posttest) than the two-sample t-test statistic which is based upon sample means (Book, 1977). The experimental group improved on the TIPS between pretest/posttest (t = +4.42). This improvement was highly significant, since it exceeded the critical decision point (±1.96) on the normal distribution curve for 95% confidence. A further comparison was made between parallel questions on the TIPS-I and TIPS-II for the comparative groups (Table 2, Appendix E). Once again, the results from the experimental group were

statistically significant for the paired-sample t-test in the gain scores for parallel questions ($t_{parallel}$ = +3.50) in contrast to the control ($t_{parallel}$ = +0.59). Therefore, the null hypothesis (Sub-hypothesis Ib) was rejected in favor of the alternate. Scientific (environmental) problem-solving skills, as measured by the TIPS, will improve with repeated exposure to microcomputer simulations with community college students.

Sub-hypothesis Ic compared the TIPS gain scores between the comparative groups. The purpose of the control group in this quasi-experimental design was to address gains due to Hawthorne effects. This sub-hypothesis was tested in three different ways. First, the paired-sample t-test statistic compared the individual gain scores of the control group with those reported previously for the experimental group. The results ($t_{raw\ scores}$= +0.19; $t_{parallel}$= +0.59) failed to reject the null hypothesis (Sub-hypothesis Ic). Based upon this test statistic, the control group did not improve between the TIPS pretest and posttest. A comparison of these results for the control group ($t_{raw\ scores}$ = +0.19) vs. the experimental group ($t_{raw\ scores}$ = +4.42), on a normal distribution curve (two-tailed t-test), confirmed the significant improvement in problem-solving by the experimental group over the control group. The same confirmation was made when the parallel questions on the TIPS were compared. Further support for this conclusion was made by comparision of a two-sample t-statistic on the sample means for both groups. The results for the experimental group (t = -2.54) also led to the rejection of the null hypothesis (Sub-hypothesis Ic). In other words, the experimental group scored significantly higher than the control on the TIPS posttest.

Lastly, the gain scores for both groups were compared by the two-sample t-test statistic. These results indicated that the mean gain scores were significantly different between the two groups ($t_{two\text{-}sample} = -7.49$). Negative values were encountered because $\overline{X}_1$ was assigned to the control group and $\overline{X}_2$ to the experimental group. This was done for consistency. The null hypothesis (Sub-hypothesis Ic), therefore, was rejected in favor of its alternate. The gain in TIPS scores was significantly higher for the experimental group than the control. A summary of the results from the test statistics used for Hypothesis I is found in Table 3.

The group mean subtest gain scores for the TIPS are summarized in Table 4. Overall, the experimental group improved in all subsections compared to the control group. The most noted improvements were in interpreting data and graphs (+1.53), designing investigations (+0.68), and formulating hypotheses (+0.62). Since the computer simulators directed students to focus on these skills as part of the scientific method, the results were reasonable. The control group showed some improvements in the first two areas (interpretation +0.29, design +0.42), but performed poorly in the subsections on identifying variables, formulating hypotheses, and operationally defining variables. Similarly, strong gains were observed in the experimental group for the derived subsection on the TIPS (Table 11).

Hypothesis II

The results from Hypothesis I raised a subordinate question. Could the problem-solving heuristics learned with the simulators be expanded into tangential domains (Hypothesis II)? The Cornell Critical Thinking Test was used to measure improvements in such expansion. But, before addressing this hypothesis, the construct validity for the instrument had to be determined.

The construct validity was established with a larger data base: Composite Sample A. This sample included the pretest scores, both TIPS-I and Cornell-Z from 86 subjects who began the study (Table 6). Fifty-eight of the subjects in this sample were also in the comparative groups. A scatter diagram was plotted to reveal if any relationship existed between the TIPS and Cornell tests. The graph (Figure 4) indicated a moderately positive trend which was further verified by the Pearson product-moment correlation coefficient (r = 0.50). A linear regression plot was also constructed via *Cricket Graph* software.

Scatter diagrams and correlation analyses were then carried out with data from the comparative groups for the pretest and posttest scores (Figures 6, 7, 8 & 9). Pretest correlations varied significantly between samples (Composite A = 0.50; Control = 0.75; and Experimental = 0.29). This was not expected considering the similar mean scores for both pretests in each group listed in Table 5 & 12 (TIPS: Composite A = 22.56; Control = 22.38; Experimental = 23.47 | Cornell: Composite A = 25.94; Control = 25.54; Experimental = 28.44). It is reasonable to

assume that small sample size limits the value of statistical analysis in this situation. Subsequently, the construct validity of the Cornell test was re-examined on a logical basis.

The original subsections for the TIPS, Cornell-Z, and Watson-Glaser tests were compared (Table 8). A review of the constructs indicated some overlap between the two tests used in this study. This conclusion was further supported by the results from Composite A. The correlation coefficient obtained from that sample ($r = 0.50$) implied a 25% overlap in constructs between the two tests. However, this degree of overlap was not consistent with that obtained from the comparative groups (Control = 55%; Experimental = 8%).

The researcher then reclassified items on the TIPS and Cornell tests according to the objectives from the computer simulator packages (Appendix B, C & D). From this refinement, a subset of test items was isolated and regrouped to show common constructs (Appendix H). The similar mean for the refined Cornell in the three groups also supported the construct validity of the Cornell test (Table 12). Refinement of the Cornell test, however, did not appreciably affect the correlations with the TIPS for any group. The construct validity of the Cornell test for this study was accepted on a logical basis because of three factors: (1) the degree of overlap found in the composite sample, (2) the similar mean on the refined test, and most importantly, (3) the review process for comparing the test items with the simulator objectives.

Hypothesis II required an examination of the correlation between the gain scores on the TIPS with gain scores on the Cornell-Z (Figures 12, 13, 16 & 17, and Table 12). The raw score correlations for the experimental group significantly improved (r = 0.29 -> 0.60) between pretest/posttests, whereas the control group regressed (r = 0.75 -> 0.45). The strong increase in the Pearson-r value for the experimental group, however, did not translate into improved raw scores on the Cornell. Actually, the experimental group had a mean loss on the post Cornell (-0.56). The control group had an even greater mean loss for the same test (-1.88). Such a mean loss was unexpected due to the gain on the TIPS and the degree of overlap between the construction of two tests.

The more important statistic, relative to hypothesis II, was a comparison of the gain score correlations between the comparative groups. Since the data contained negative gains, the scores were transformed (+15 points). The formula for Pearson-r would not yield true correlations otherwise. Considering the level of standard error of Pearson-r for both groups, the gain score correlations were significantly different from zero for their respective sample size. However, the gain score correlations were virtually equal (Control = 0.38, Experimental 0.34). The stability of these statistical results could have been affected by small sample size. For this reason, the correlations for the TIPS vs. refined Cornell were also considered analogous. The null hypothesis was not rejected at this point.

Because of the uncertainty from the statistical results, there were implications for a Type II error. One consideration, for this type error,

was the difference in sample means for each test and their relationship to gains in percentile. The experimental group mean scores on the Cornell were pretest = 28.44 and posttest = 27.88. This translates into norm-referenced percentile ranks between 50-55th (Ennis, *et al.*, 1985). On the other hand, the same scores for the control group (pretest = 25.54, posttest = 23.67) were between the 5-25th percentile. These percentile ranks are estimates, because the Cornell-Z referenced populations were still limited. On the average, students in the experimental group were working at a higher percentile rank than those of the control. In fact, a higher gain for the experimental group would be more difficult to achieve than for the control. The null hypothesis II could not be rejected, therefore, based upon statistical analysis. Another consideration against accepting the null hypothesis was an external influence on the test instrument. Hypothesis III was formulated to investigate one such influence.

Hypothesis III

This hypothesis tested if the process of learning problem-solving heuristics was affected by student reading level. The TIPS and Cornell tests differed in format. The TIPS was comprised of test items which had short phrases followed by short statements. In contrast, the Cornell test required students to comprehend several paragraphs of information. Afterwards, they had to choose from responses which were more complex than those found on the TIPS. Placement data indicated a wide range in reading level among community college students. Correlations between the TIPS, Cornell, and reading ability were examined using

another composite sample. Composite Sample B was composed of thirty-one students from the original population. Based on Nelson-Denny scores, the mean reading level for the sample was grade 12 with a two-grade level standard deviation (Table 13). The sample had a bimodal distribution at reading grades 10 and 13 (Figure 18b). All of the Nelson-Denny scores were not available due to the admission process at the college. The frequency distribution for the vocabulary, reading comprehension, and total Nelson-Denny scores were also summarized in Figure 18.

Sub-hypothesis IIIa tested if the TIPS was subject to a reading level bias. Scatter diagrams were plotted to establish if there was a relationship between the TIPS, vocabulary, reading comprehension, and total Nelson-Denny scores (Figures 19, 21, 23, and Table 14). Both the scatter diagrams and the Pearson-r coefficient indicated minimal correlations between the TIPS and all sections of the Nelson-Denny test (vocabulary r = 0.28, reading comprehension r = 0.27, total score r = 0.31). (*N.B.*, The lowest Pearson-r value for n = 31 is 0.36, at a 95% level of significance.) Therefore, the null hypothesis (Sub-hypothesis IIIa) was not rejected based upon the data obtained from Composite Sample B. Performance on the TIPS was independent of reading ability for community college students.

A similar analysis was done for Sub-hypothesis IIIb concerning the Cornell test (Figures 20, 22 & 24). The correlation coefficients (Table 14) indicated a greater relationship between the Cornell and reading ability than was seen in the TIPS (vocabulary r = 0.47, reading

comprehension r = 0.47, total score r = 0.52). Based upon Composite B, the null hypothesis (sub-hypothesis IIIb) was rejected in favor of its alternate. Reading level presented a bias to community college students tested by the Cornell Critical Thinking Level-Z.

Evidence from Hypothesis II and Sub-Hypothesis IIIb indicated the Cornell-Z was subject to an outside influence. Results on the Cornell-Z should not be considered a definite measure of problem-solving expansion. The support of a reading bias further weighted the argument for an inconclusive decision under Hypothesis II, rather than acceptance of the null hypothesis. It cannot be concluded that students were unable to expand problem-solving skills learned via simulation to new applications, because the instrument used to measure that ability was subject to at least one bias.

Summary

The statistical hypothesis testing supported the following decisions:

1. The control group was initially representative of the experimental group in scientific problem-solving, as measured by the TIPS.

2. Students in the experimental group demonstrated a significant increase in scientific problem-solving after being repeatedly exposed to environmental microcomputer simulators.

3. The gain in scientific problem-solving, as measure by the TIPS, was significantly higher for the experimental group than for the control.

4. There was a moderately positive correlation between the TIPS and Cornell Level-Z tests.

5. The Cornell-Z was subject to an external reading level bias. Therefore, the question about expanding the acquired scientific problem-solving skills is left unresolved. The data was inconclusive.

TABLE 1. Raw Scores, Gain Scores, and Descriptive Statistics on Data from Test of Integrated Process Skills (TIPS)

Subject	CONTROL GROUP			EXPERIMENTAL GROUP		
	Pretest TIPS-I	Posttest TIPS-II	Gain	Pretest TIPS-I	Posttest TIPS-II	Gain
1	25	10	-15	20	20	0
2	13	18	+5	29	31	+2
3	28	30	+2	17	24	+7
4	32	25	-7	16	26	+10
5	25	18	-7	27	22	-5
6	22	24	+2	30	31	+1
7	24	24	0	15	21	+6
8	12	15	+3	28	30	+2
9	25	26	+1	22	34	+12
10	29	30	+1	26	27	+1
11	27	34	+7	31	30	-1
12	10	18	+8	18	24	+6
13	22	23	+1	19	30	+11
14	26	28	+2	22	28	+6
15	30	25	-5	14	14	0
16	30	28	-2	26	31	+5
17	14	17	+3	22	28	+6
18	20	19	-1	27	33	+6
19	21	14	-7	14	18	+4
20	10	13	+3	16	19	+3
21	23	25	+2	15	20	+5
22	22	31	+9	21	23	+2
23	23	22	-1	30	34	+4
24	24	25	+1	32	32	0
25				27	25	-2
26				32	34	+2
27				11	20	+9
28				22	21	-1
29				29	30	+1
30				33	34	+1
31				26	24	-2
32				25	23	-2
33				25	29	+4
34				31	31	0
Number of Test Items	36					
Σ Gain			+5			+103
Mean	22.38	22.58	+0.21	23.47	26.50	+3.03
Standard Deviation	6.34	6.25	5.38	6.24	5.44	4.00
Variance	40.20	39.06	29.04	38.94	29.59	16.00
Paired-Sample t			+0.19			+4.42

TABLE 2. Raw Scores, Gain Scores, and Descriptive Statistics on Data from Parallel Questions for the Test of Integrated Process Skills

Subject	CONTROL GROUP			EXPERIMENTAL GROUP		
	Pretest	Posttest	Gain	Pretest	Posttest	Gain
1	17	7	-10	13	13	0
2	10	13	+3	21	22	+1
3	20	23	+3	12	16	+4
4	23	17	-6	10	19	+9
5	18	13	-5	18	16	-2
6	15	17	+2	21	23	+2
7	15	17	+2	9	15	+6
8	10	11	+1	18	22	+4
9	16	19	+3	15	24	+9
10	23	23	0	20	20	0
11	20	24	+4	24	21	-3
12	5	13	+8	12	16	+4
13	16	16	0	13	23	+10
14	19	21	+2	13	21	+7
15	20	19	-1	10	21	0
16	22	20	-2	18	21	+3
17	11	13	+2	16	23	+7
18	13	14	+1	20	23	+3
19	16	8	-8	10	15	+5
20	8	11	+3	13	14	+1
21	13	18	+5	9	12	+3
22	15	23	+8	14	15	+1
23	16	17	+1	22	24	+2
24	19	16	-3	24	23	-1
25				22	19	-3
26				22	25	+3
27				6	12	+6
28				16	15	-1
29				21	21	0
30				21	26	+5
31				17	16	-1
32				17	18	+1
33				17	22	+5
34				23	22	-1
Means	15.8	16.4	+0.54	16.4	19.0	+2.62
Paired-Sample t			+0.59			+3.50
Number of Test Items		26				

TABLE 3. Summary of Test Statistics Used for Hypothesis I

Sub-hypotheses	Tests & Group	Test Statistic	*d.f.*	Critical Value	Results	Decision
Ia	TIPS-I Control vs. Experimental	F-test on	(23, 33, .025)	+2.14	+1.03	variances equal
		t-test for two independent sample means	56	±1.96	-0.17	fail to reject
Ib	Pre-/Post TIPS	t-test for paired-samples	33	±1.96	+4.42	reject null
Ic	Pre-/Post TIPS Control	t-test for paired-samples	23	±1.96	+0.19	fail to reject
	Mean Posttest TIPS Control & Experimental	F-test	(23, 33, .025)	+2.14	+1.32	variances equal
		t-test for two independent sample means	56	±1.96	+2.54	reject null
	Gain Scores TIPS Control & Experimental	F-test	(23, 33, .025)	+2.14	+1.74	variances equal
		t-test for two independent sample means	56	±1.96	-7.49	reject null

TABLE 4. Mean Subtest Gain Scores for Test of Integrated Process Skills†

Subsection	CONTROL GROUP			EXPERIMENTAL GROUP		
	TIPS-I	TIPS-II	Gain	TIPS-I	TIPS-II	Gain
Identify Variables	7.17	6.79	-0.38	7.56	7.71	+0.15
Identify & State Hypotheses	6.04	6.00	-0.04	6.06	6.68	+0.62
Operationally Define Variables	3.63	3.54	-0.08	4.26	4.38	+0.12
Designing Investigations	1.88	2.29	+0.42	1.94	2.62	+0.68
Interpretation of Data & Graphs	3.67	3.96	+0.29	3.56	5.12	+1.53

† Dillashaw, F. And J. Okey, 1980

TABLE 5. **Descriptive Statistics for Control and Experimental Groups**

Test	Number of Test Items	CONTROL GROUP				EXPERIMENTAL GROUP			
		Mean	Standard Deviation	Median	Range	Mean	Standard Deviation	Median	Range
TIPS-I	36	22.38	6.34	23.5	22	23.47	6.24	25.0	22
TIPS-II	36	22.58	6.25	24.0	24	26.50	5.44	27.5	20
Pretest Cornell-Z	52	25.54	4.52	25.0	17	28.44	5.96	29.0	26
Posttest Cornell-Z	52	23.67	5.23	23.5	21	27.88	5.51	27.0	19

TABLE 6. Composite Sample A: TIPS and Cornell Pretest Scores

Subject	TIPS-I	Cornell Level-Z	Subject	TIPS-I	Cornell Level-Z
1	25	26	44	13	24
2	28	23	45	32	34
3	25	25	46	22	23
4	24	33	47	12	18
5	25	28	48	29	25
6	27	32	49	10	17
7	22	22	50	26	28
8	30	29	51	30	32
9	14	25	52	20	25
10	21	22	53	10	19
11	23	28	54	22	22
12	23	27	55	24	26
13	20	26	56	29	33
14	17	26	57	16	29
15	27	31	58	30	13
16	15	19	59	28	35
17	22	30	60	26	26
18	31	34	61	18	21
19	19	26	62	22	31
20	14	30	63	26	35
21	22	32	64	27	34
22	14	21	65	16	26
23	15	33	66	21	21
24	30	27	67	32	31
25	27	29	68	32	29
26	11	34	69	22	24
27	29	37	70	33	39
28	26	18	71	25	25
29	25	26	72	31	36
30	27	21	73	28	38
31	32	27	74	22	34
32	18	21	75	24	30
33	33	32	76	24	28
34	23	21	77	28	32
35	27	17	78	17	22
36	14	6	79	25	22
37	22	26	80	21	12
38	13	16	81	31	18
39	13	12	82	17	23
40	12	19	83	29	30
41	19	21	84	11	21
42	9	18	85	24	30
43	21	26	86	21	28
Number of Test Items				36	52
Mean				22.56	25.94
Standard Deviation				±6.37	±6.42

TABLE 7. Descriptive Statistics and Gain Scores on Data from Cornell Critical Thinking Test Level-Z

Subject	CONTROL GROUP			EXPERIMENTAL GROUP		
	Pretest	Posttest	Gain	Pretest	Posttest	Gain
1	26	22	-4	26	19	-7
2	24	26	+2	33	35	+2
3	23	23	0	26	31	+5
4	34	24	-10	29	26	-3
5	25	20	-5	31	24	-7
6	23	28	+5	13	20	+7
7	33	28	-5	19	24	+5
8	18	15	-3	35	36	+1
9	28	22	-6	30	31	+1
10	25	21	-4	26	27	+1
11	32	34	+2	34	27	-7
12	17	15	-2	21	24	+3
13	22	26	+4	26	27	+1
14	28	32	+4	31	34	+3
15	29	26	-3	30	21	-9
16	32	31	-1	35	32	-3
17	25	20	-5	32	32	0
18	25	13	-12	34	31	-3
19	22	22	0	21	23	+2
20	19	29	+10	26	25	-1
21	28	22	-6	33	27	-6
22	22	24	+2	21	25	+4
23	27	24	-3	27	29	+2
24	26	21	-5	31	37	+6
25				29	25	-4
26				29	30	+1
27				34	33	-1
28				24	24	0
29				37	32	-5
30				39	38	-1
31				18	20	+2
32				25	19	-6
33				26	23	-3
34				36	37	+1
Number of Test Items	52					
Σ Gain			-45			-19
Group Mean	25.54	23.67	-1.88	28.44	27.88	-0.56
Standard Deviation	4.52	5.23	4.95	5.96	5.51	4.12
Variance	20.43	27.35	24.50	35.52	30.36	16.97

TABLE 8. Comparison of Subsections for TIPS, Cornell Level-Z, and Watson-Glaser Assessments

TIPS†	Cornell Level-Z††	Watson-Glaser†††
Identify Variables	Deduction	Inference
Identify & State Hypotheses	Semantics	Recognition of Assumptions
Operationally Defining Variables	Credability	Deduction
Designing Investigations	Induction (Judging Conclusions)	Interpretation
Graphing & Interpreting Data	Induction (Planning Experiments)	Evaluation of Arguments
	Definition & Assumption Identification	
	Assumption Identification	

† Burns, J., Okey, J. and K. WIse (1985)
†† Ennis, R., Millman, J. and T. Tomko (1985)
††† Watson, G. and E. Glaser (1980)

TABLE 9. Mean Subsection Scores and Mean Gain Scores on Derived Cornell-Z Subsections for Applications Most Closely Related to Simulator Objectives.

Derived Subsections	CONTROL GROUP			EXPERIMENTAL GROUP		
	Pretest	Posttest	Gain	Pretest	Posttest	Gain
Interpretation of Data & Draw Conclusions (not from graphs)	2.96	2.29	-0.67	3.20	2.88	-0.32
Determine Effects of Outside Interference Upon Experiment	1.92	1.63	-0.29	2.15	2.00	-0.15
Judge the Relevance of Additional Information to Experimental Design	1.29	1.21	-0.08	1.35	1.47	+0.12
Reassess Conclusions Based Upon Additional Information from Repeated Experiments	3.08	2.58	-0.58	3.06	3.18	+0.12
Number of Items 16 Group Mean	9.25	7.71	-1.54	9.76	9.52	-0.24

TABLE 10. Pretest and Posttest Mean Subsection Scores and Mean Gain Scores for the Cornell Critical Thinking Test Level- Z†

Subsection†	Control Group			Experimental Group		
	Pretest	Posttest	Gain	Pretest	Posttest	Gain
Deduction	6.04	6.04	0.0	6.97	6.59	-0.38
Semantics	3.42	2.71	-0.71	3.47	3.44	-0.03
Credability	1.42	1.17	-0.25	2.09	1.88	-0.21
Induction (Judging Conclusions)	6.62	5.46	-0.16	6.88	6.97	+0.09
Induction (Planning Experiments)	1.42	1.54	+0.12	2.09	1.79	-0.30
Definition & Assumption Identification	1.92	1.83	-0.09	2.29	2.35	-0.06
Assumption Identification	2.75	3.17	-0.42	2.85	2.85	0.0

† Ennis, R., Millman,J. and T. Tomko (1985)

TABLE 11. Mean Subsection Scores and Mean Gain Scores on Derived TIPS Subsections for Problem-Solving Skills Most Closely Related to Simulator Objectives

Derived Subsections	CONTROL GROUP			EXPERIMENTAL GROUP		
	TIPS-I	TIPS-II	Gain	TIPS-I	TIPS-II	Gain
Isolate & Operationally Define Variables	5.71	5.13	-0.58	5.94	6.38	+0.44
Interpret Data Tables and Approximate Trends in Graphs/Tables	1.42	2.08	+0.67	0.91	2.00	+1.09
Analyze Graphs	2.25	2.33	+0.08	2.38	2.56	+0.18
Experimental Design	3.04	3.63	+0.58	3.18	4.12	+0.94
Formulate Hypotheses	3.42	3.46	+0.04	3.50	3.88	+0.38
Number of Test Items 26 Group Mean	15.83	16.16	+0.33	15.91	18.94	+3.03

TABLE 12. Pearson Product-Moment Correlation Coefficient (r) between Raw Scores, Refined Scores, and Gain Scores of the TIPS and Cornell Level-Z, and Descriptive Statistics

	Control n = 24	Experimental n = 34	Composite Sample A n = 86
CORRELATIONS			
Raw Scores			
TIPS-I vs. Pre-Cornell	0.75	0.29	0.50
TIPS-II vs. Post-Cornell	0.45	0.60	
Refined Cornell			
TIPS-I vs. Pre-Cornell	0.65	0.28	0.45
TIPS-II vs. Post-Cornell	0.60	0.55	
Gain Scores			
Total TIPS vs. Total Cornell	0.38	0.34	
Total TIPS vs. Refined Cornell	0.42	0.27	
MEAN SCORES			
TIPS-I	22.38 ± 6.3	23.47 ± 6.2	22.56 ± 6.4
TIPS-II	22.58 ± 6.3	26.50 ± 5.4	
Pre-Cornell	25.54 ± 4.5	28.44 ± 6.0	25.94 ± 6.4
Post-Cornell	23.67 ± 5.2	27.88 ± 5.5	
Refined Pre-Cornell	9.20 ± 2.0	9.74 ± 2.9	9.10 ± 2.8
Refined Post-Cornell	7.67 ± 2.9	9.50 ± 2.7	

TABLE 13. Composite Sample B: Descriptive Statistics for Comparison of Available Nelson-Denny Reading Scores with Cornell-Z and TIPS Pre-Assessements

Subject	Cornell	Vocabulary	Reading Comprehension	Nelson-Denny Total	Grade Level	TIPS-I
1	21	20	15	50	14.7	27
2	30	48	26	100	15.0	24
3	32	31	24	79	13.9	33
4	32	39	22	83	14.2	28
5	17	21	14	49	10.4	27
6	6	6	6	18	6	14
7	26	23	13	49	10.4	25
8	24	18	13	44	9.5	13
9	23	33	24	81	14	22
10	33	18	15	48	10.2	24
11	18	25	12	49	10.4	12
12	28	27	18	63	12.7	25
13	25	40	16	72	13.4	29
14	17	20	17	54	11.3	10
15	22	32	17	66	13.0	22
16	25	19	16	51	10.7	20
17	27	41	17	75	13.6	23
18	26	37	21	79	13.9	24
19	26	26	12	50	10.6	20
20	26	32	19	70	13.3	17
21	29	24	17	58	12.0	16
22	31	16	11	38	8.5	27
23	19	22	30	82	14.1	15
24	26	27	15	57	11.8	26
25	34	45	25	97	15.0	31
26	26	50	22	94	15.0	19
27	31	56	19	94	15.0	22
28	34	35	19	73	13.5	27
29	21	20	16	52	10.9	21
30	27	23	15	53	11.1	30
31	39	25	24	73	13.5	33
Numer of Items	52					36
Mean	25.84	29.00	17.77	64.55	12.3	22.77
Standard Deviation	6.46	11.30	5.18	19.25	2.2	6.10
Median	26	26	17	63	13	24

TABLE 14. Composite Sample B: Pearson Product-Moment Correlation Coefficient (r) between Nelson-Denny Subsections, Cornell Level-Z, and TIPS-I

	NELSON-DENNY SCORES		
Pretest	Vocabulary	Reading Comprehension	Total Score
Cornell Level-Z	0.47	0.46	0.52
TIPS-I	0.28	0.27	0.31

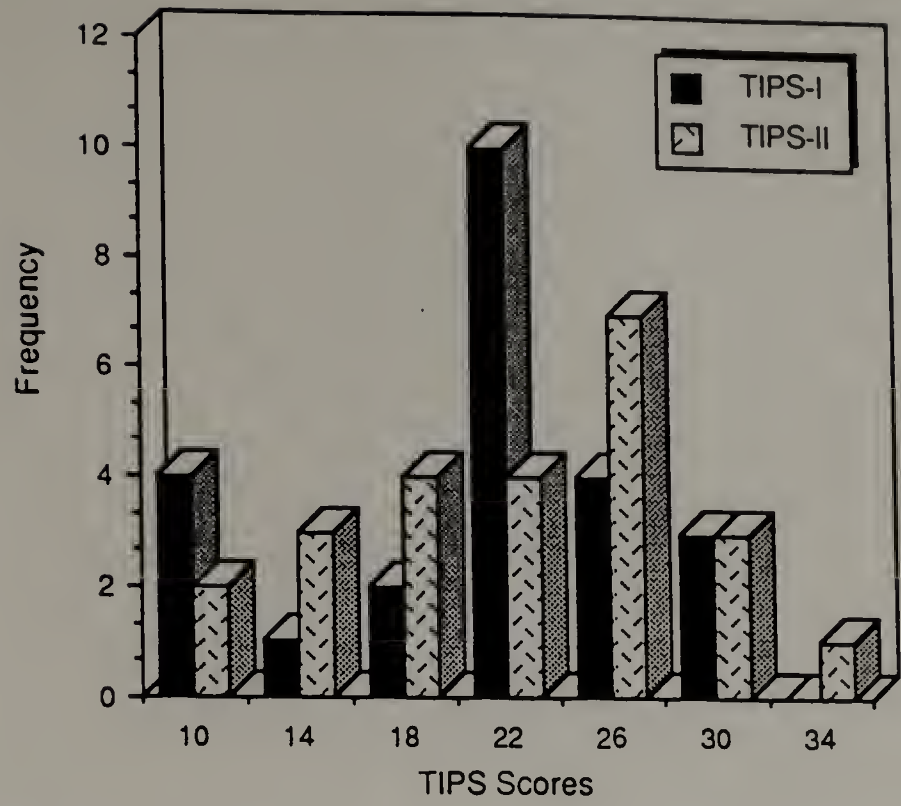


FIGURE 2. Control Group: Frequency Distribution of TIPS Pretest/Posttest Scores

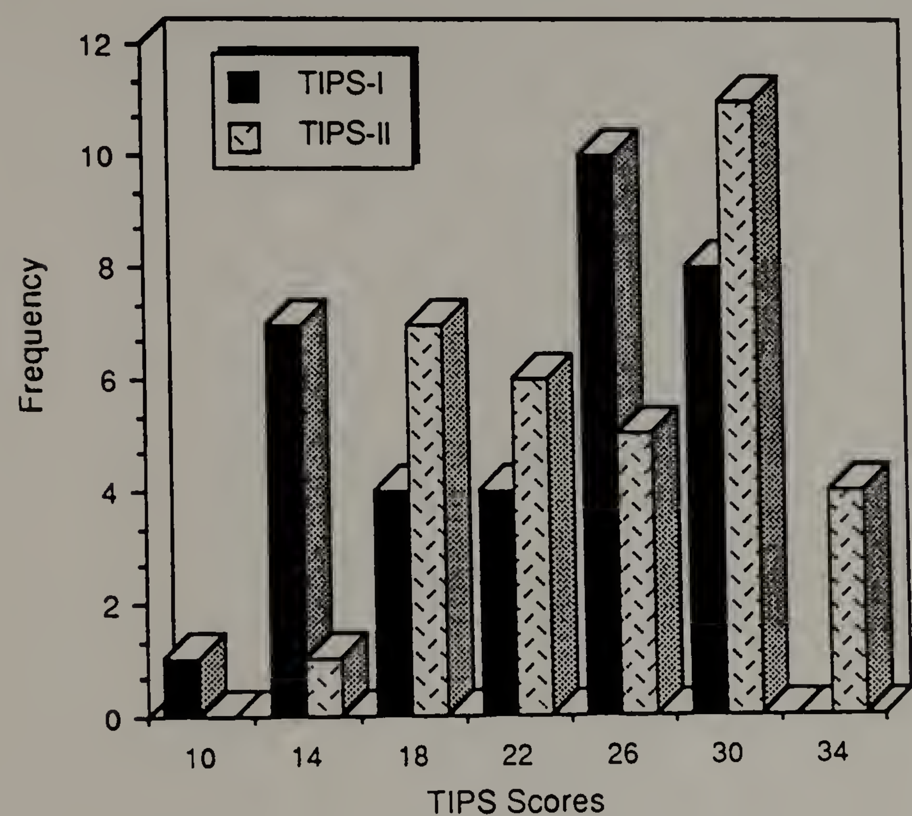


FIGURE 3. Experimental Group: Frequency Distribution of TIPS Pretest/Posttest Scores

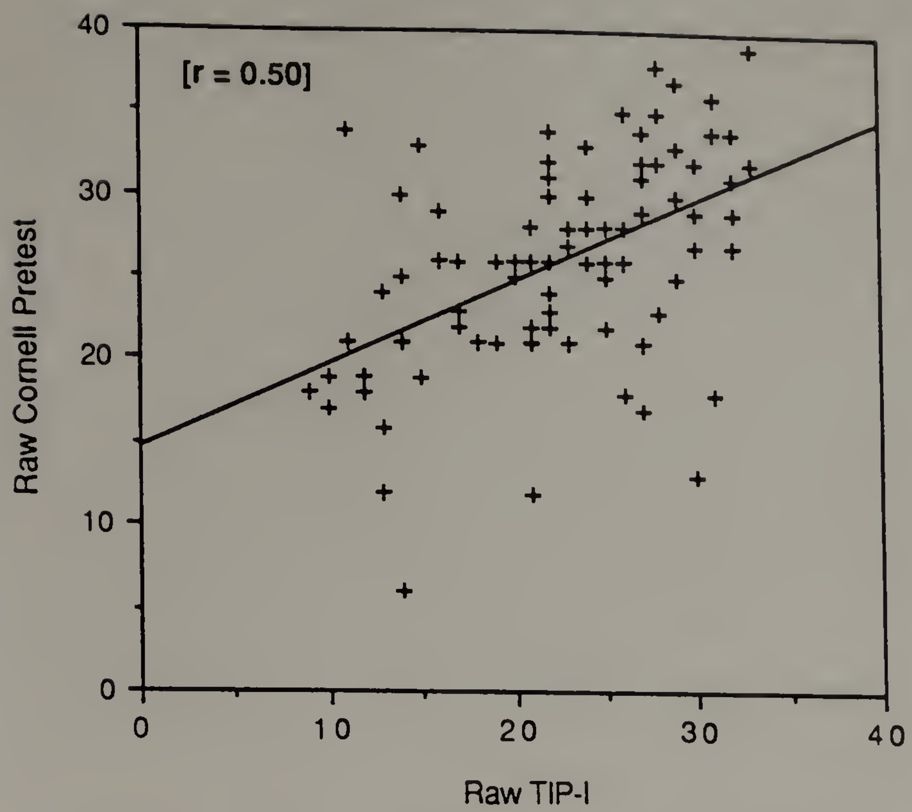


FIGURE 4. Composite Sample A: Correlation of Pretest Scores between TIPS-I and Cornell

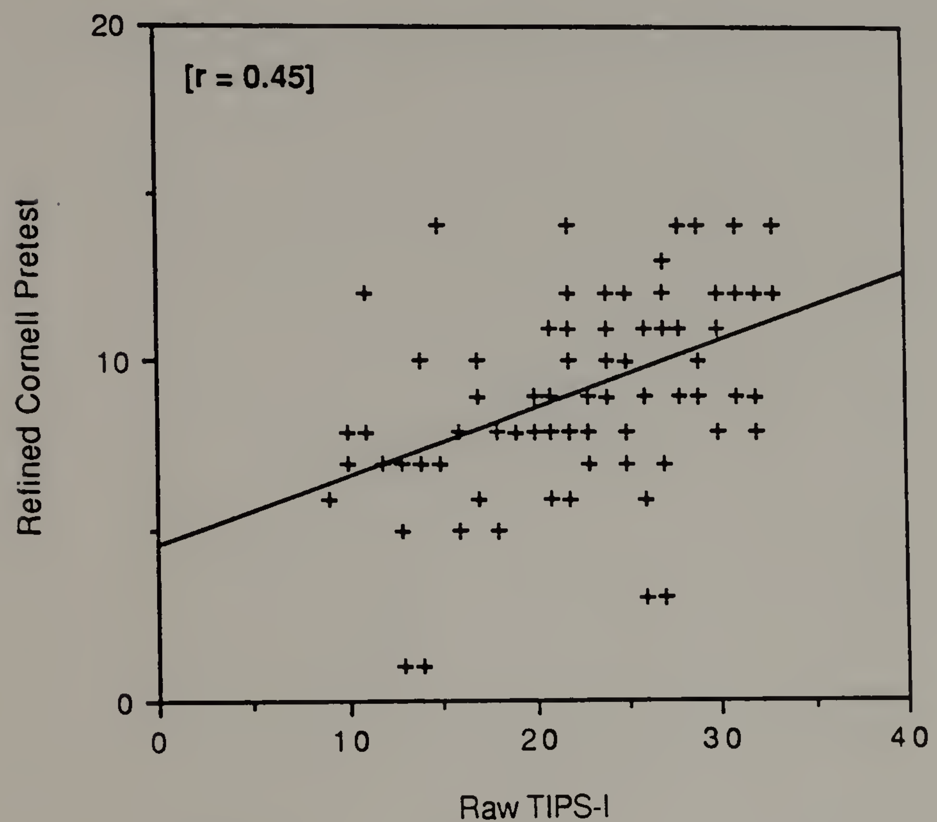


FIGURE 5. Composite Sample A: Correlation of Pretest Scores between TIPS-I and Refined Cornell

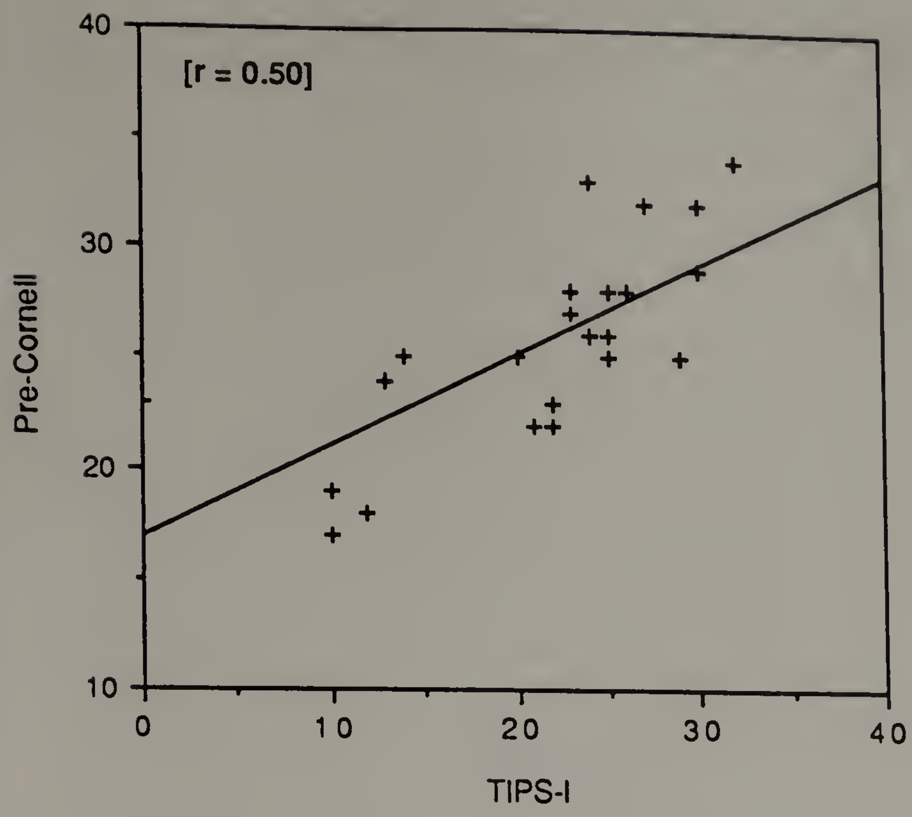


FIGURE 6. Control Group: Scatter Diagram of Pretest Scores for TIPS-I vs. Cornell

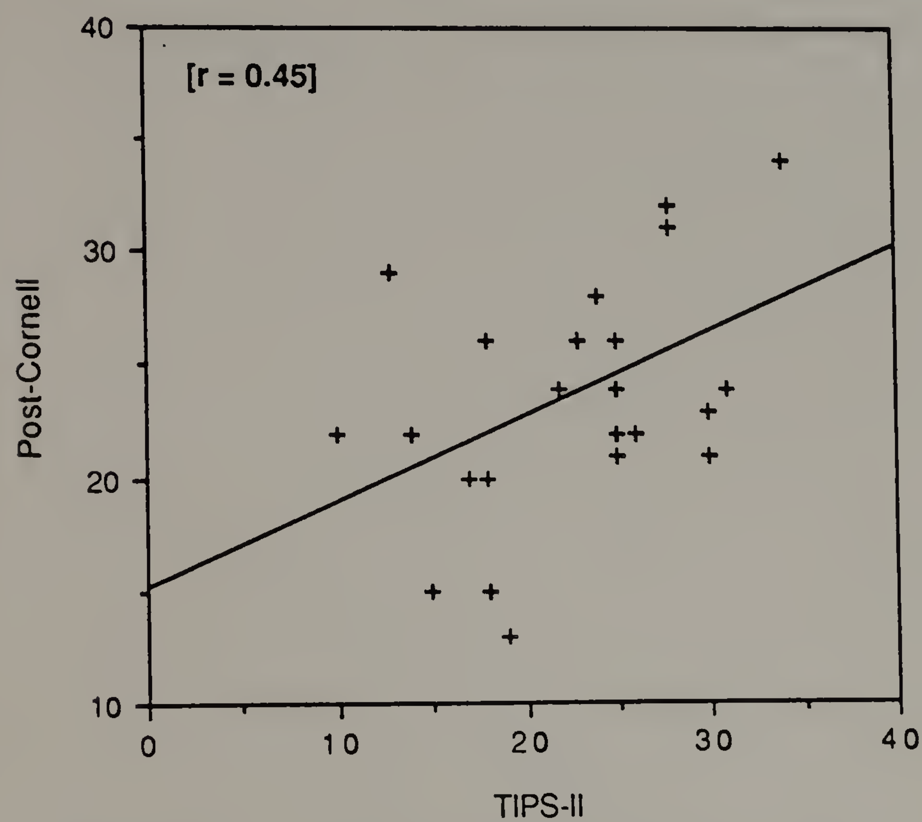


FIGURE 7. Control Group: Scatter Diagram of Posttest Scores for TIPS-II vs. Cornell

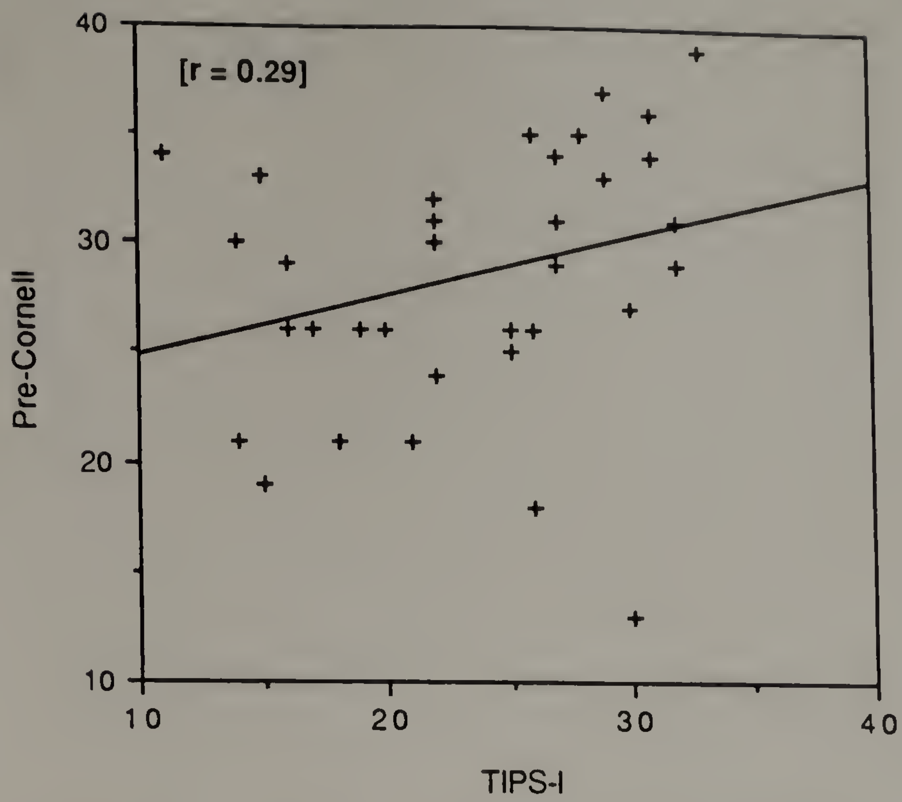


FIGURE 8. Experimental Group: Scatter Diagram of Pretest Scores for TIPS-I vs. Cornell

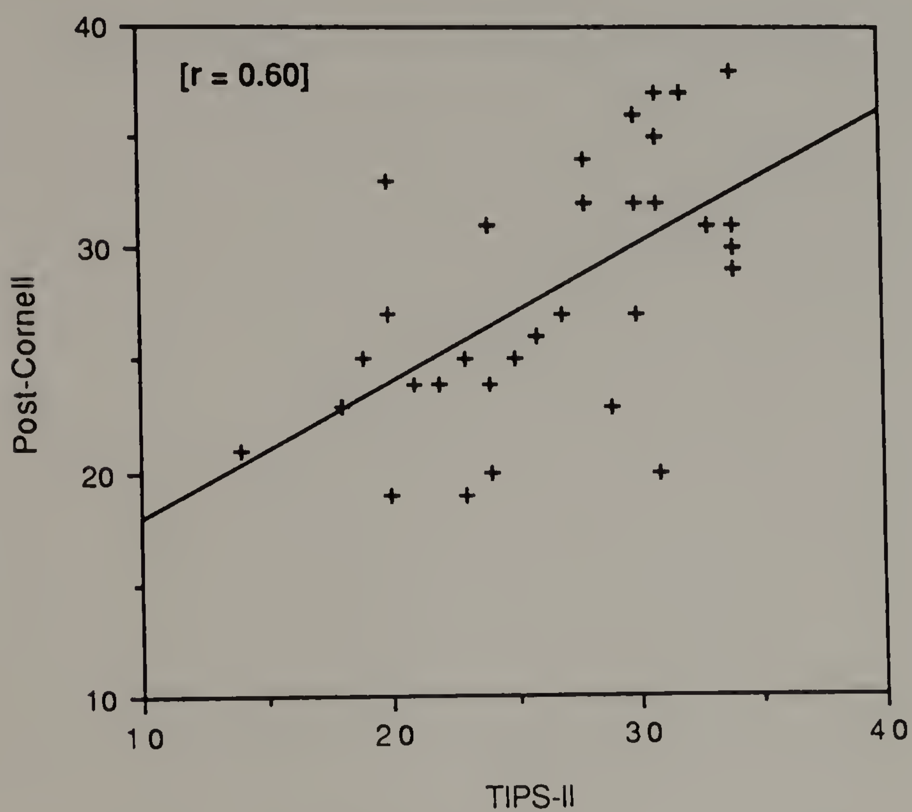


FIGURE 9. Experimental Group: Scatter Diagram of Posttest Scores for TIPS-II vs. Cornell

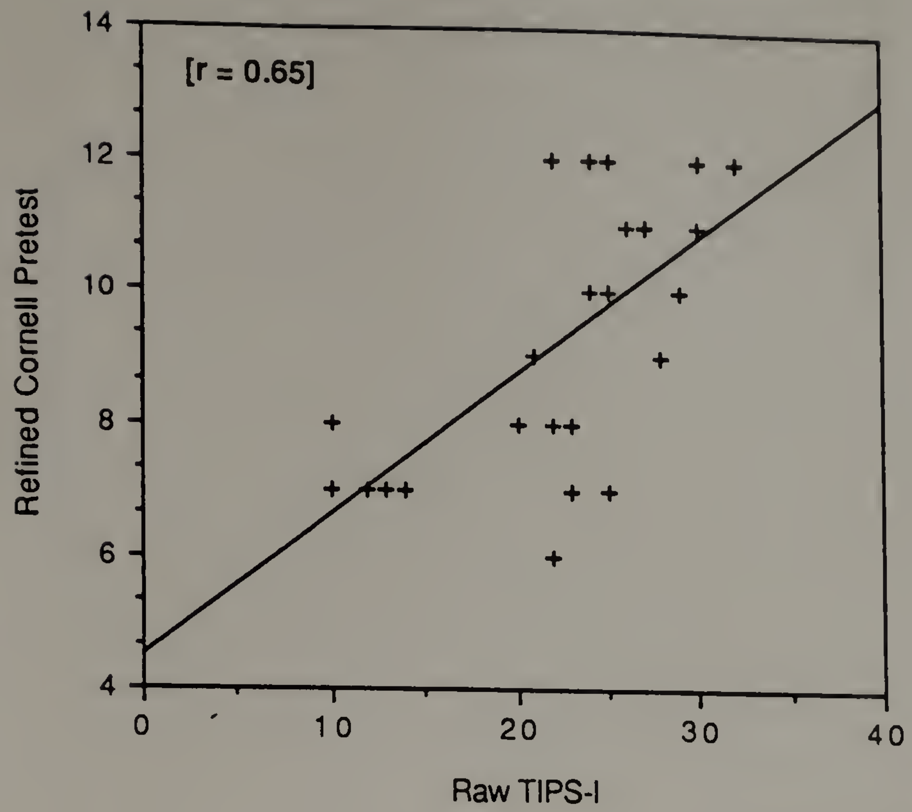


FIGURE 10. Control Group: Correlation of Pretest Scores between Raw TIPS-I and Refined Cornell Pretest Scores

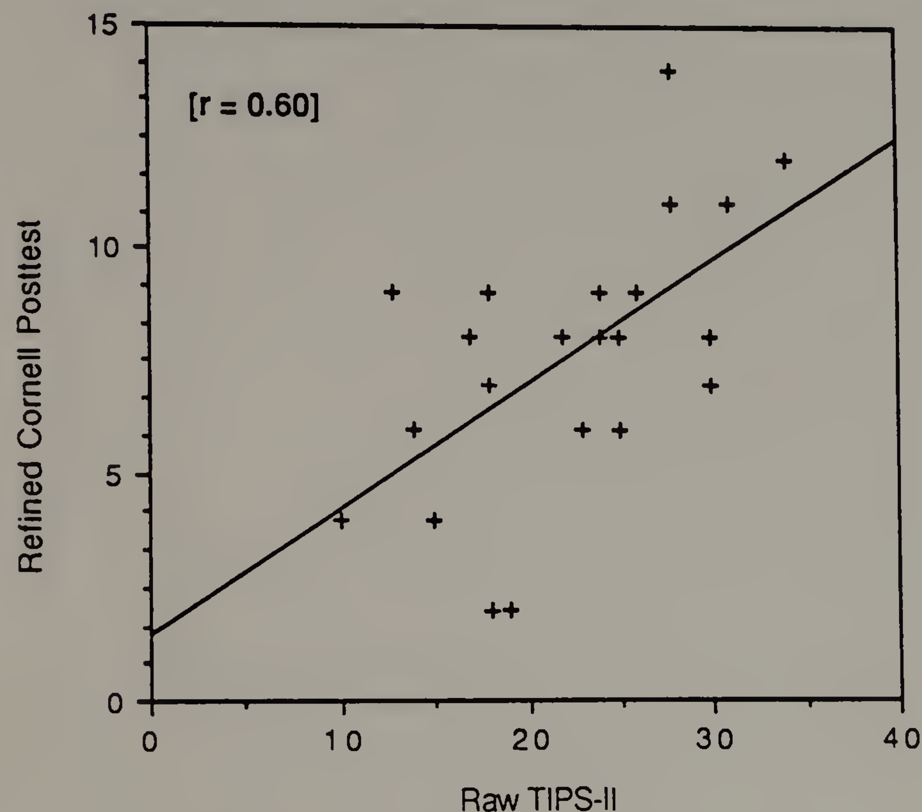


FIGURE 11. Control Group: Correlation of Posttest Scores between Raw TIPS-II and Refined Cornell

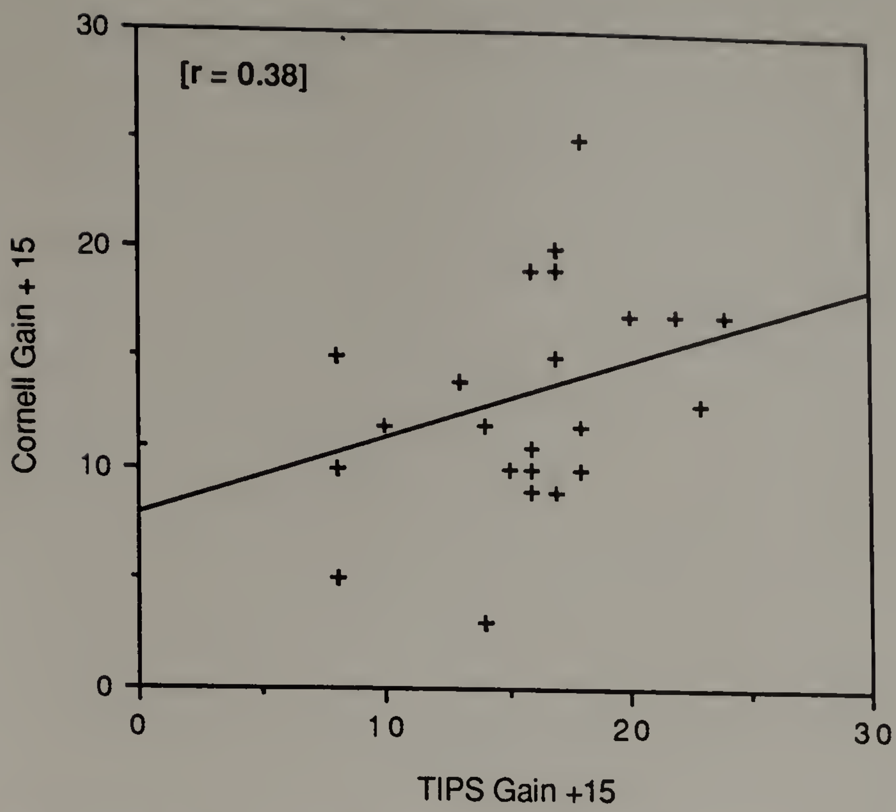


FIGURE 12. Control Group: Correlation of Gain Scores (Transformed) between TIPS and Cornell

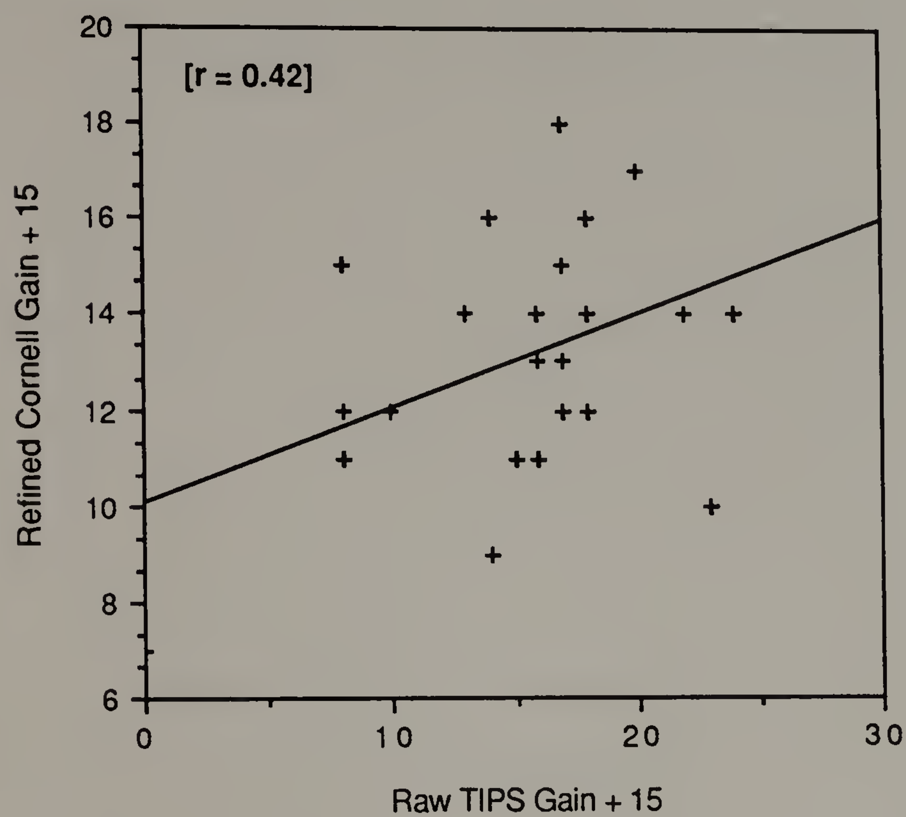


FIGURE 13. Control Group: Correlation of Gain Scores (Transformed) between TIPS and Refined Cornell

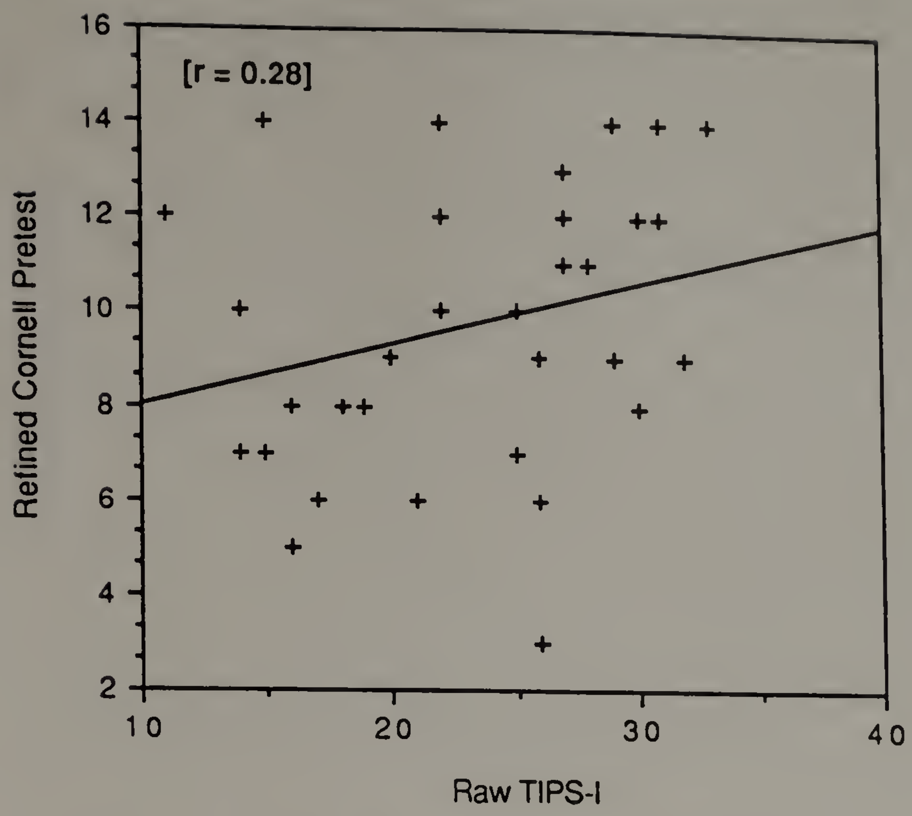


FIGURE 14. Experimental Group: Correlation of Pretest Scores between TIPS-I and Refined Cornell

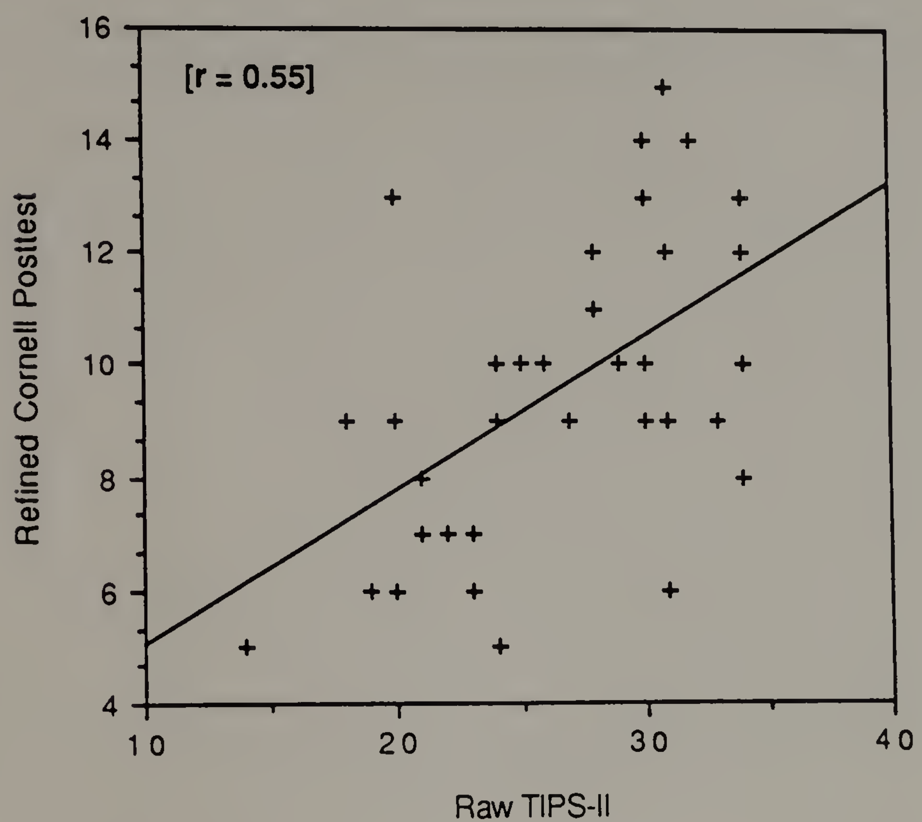


FIGURE 15. Experimental Group: Correlation of Posttest Scores between TIPS-II and Refined Cornell

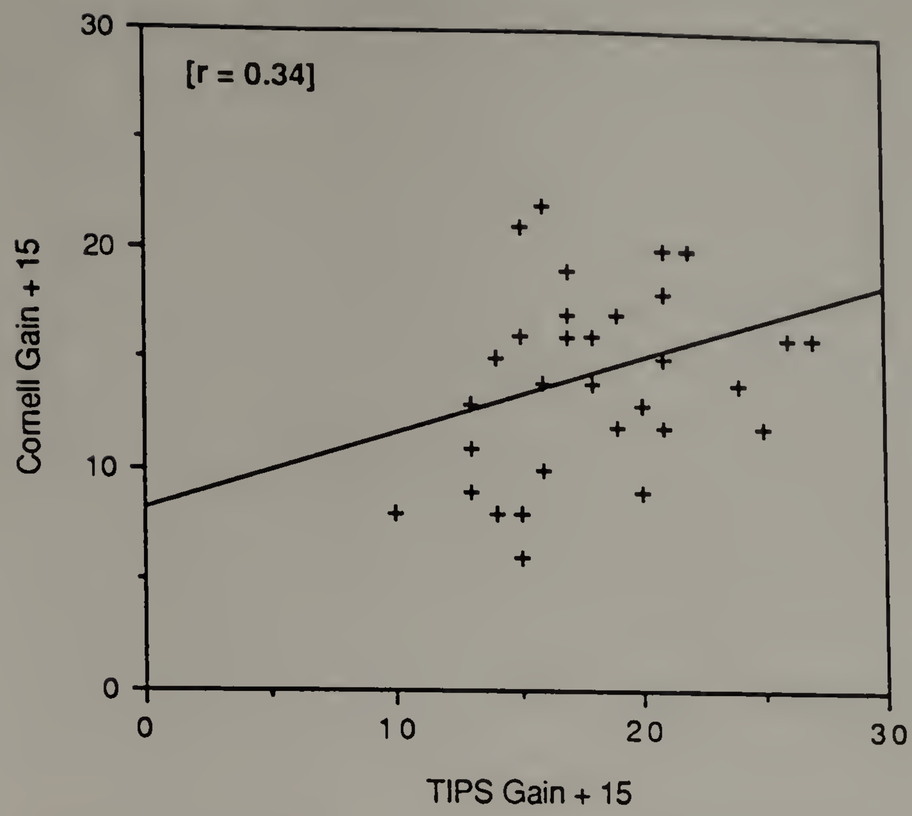


FIGURE 16. Experimental Group: Correlation of Gain Scores (Transformed) between TIPS and Cornell

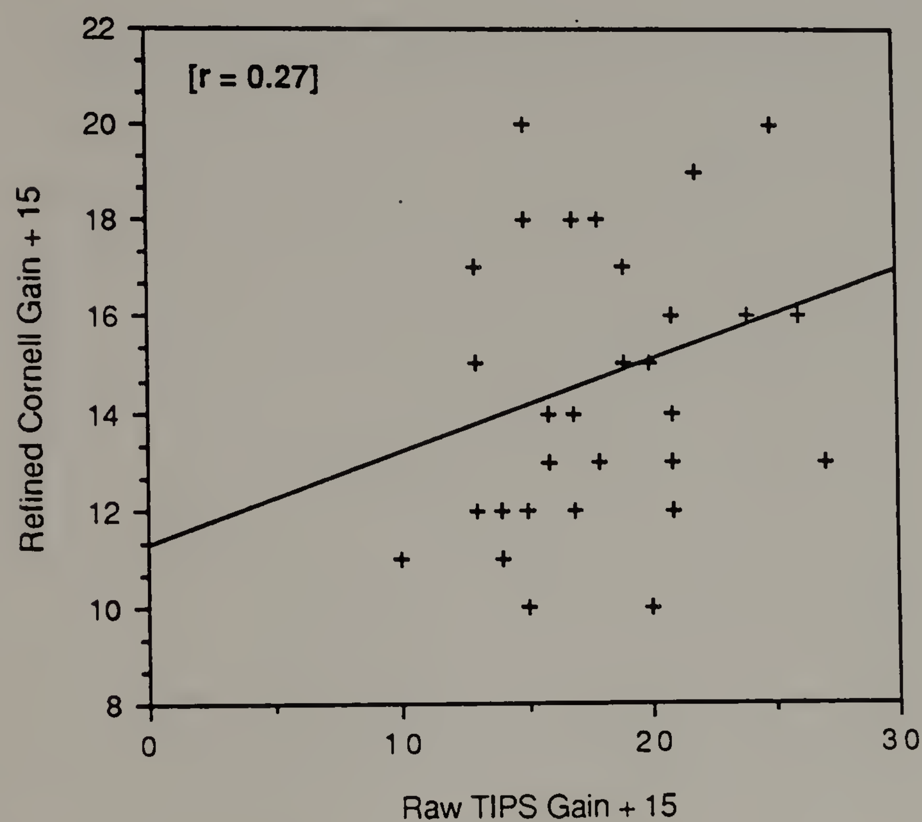


FIGURE 17. Experimental Group: Correlation of Gain Scores (Transformed) between TIPS and Refined Cornell

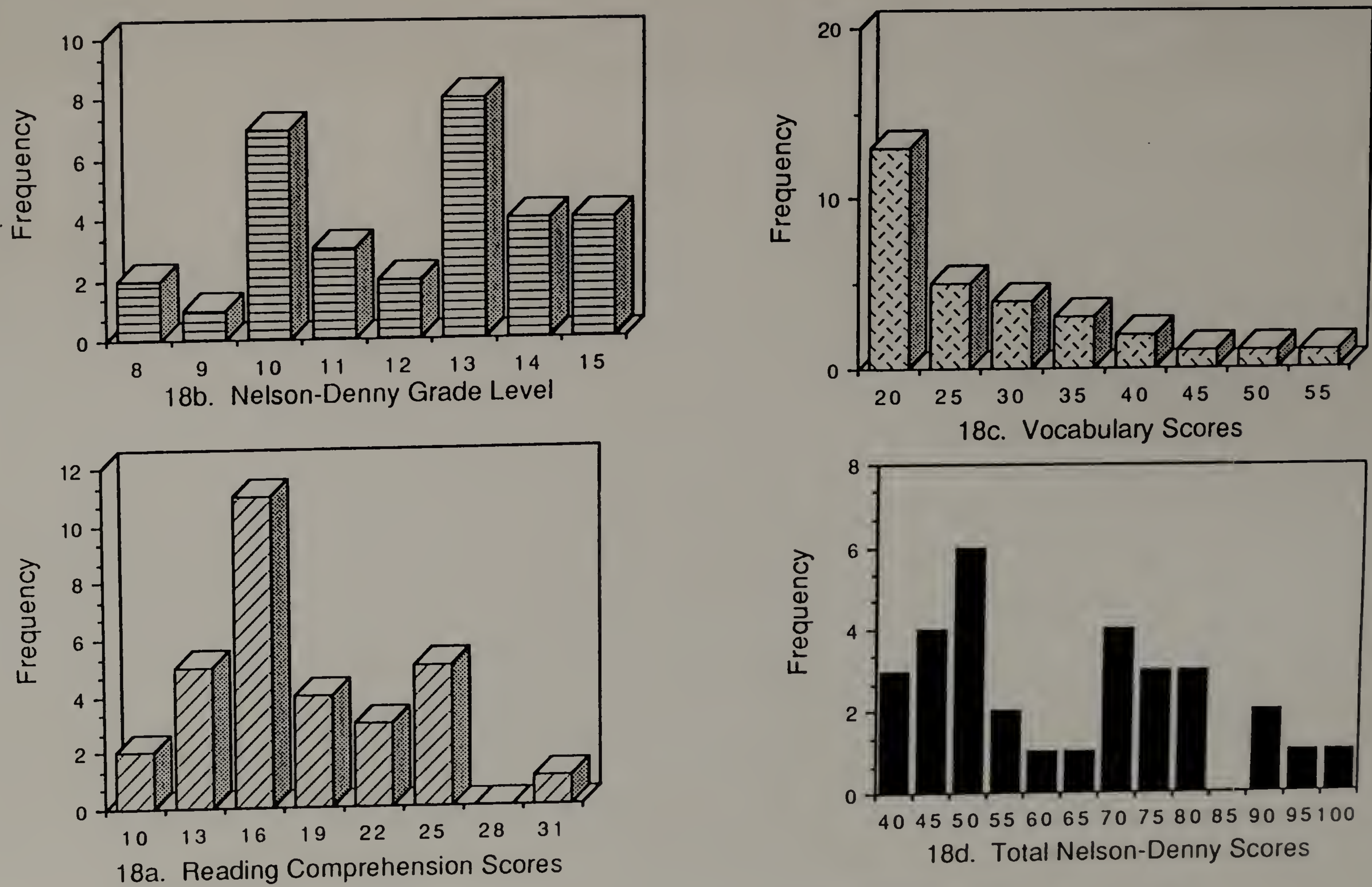


FIGURE 18. Composite Sample B: Frequency Distributions of Nelson-Denny Subscores

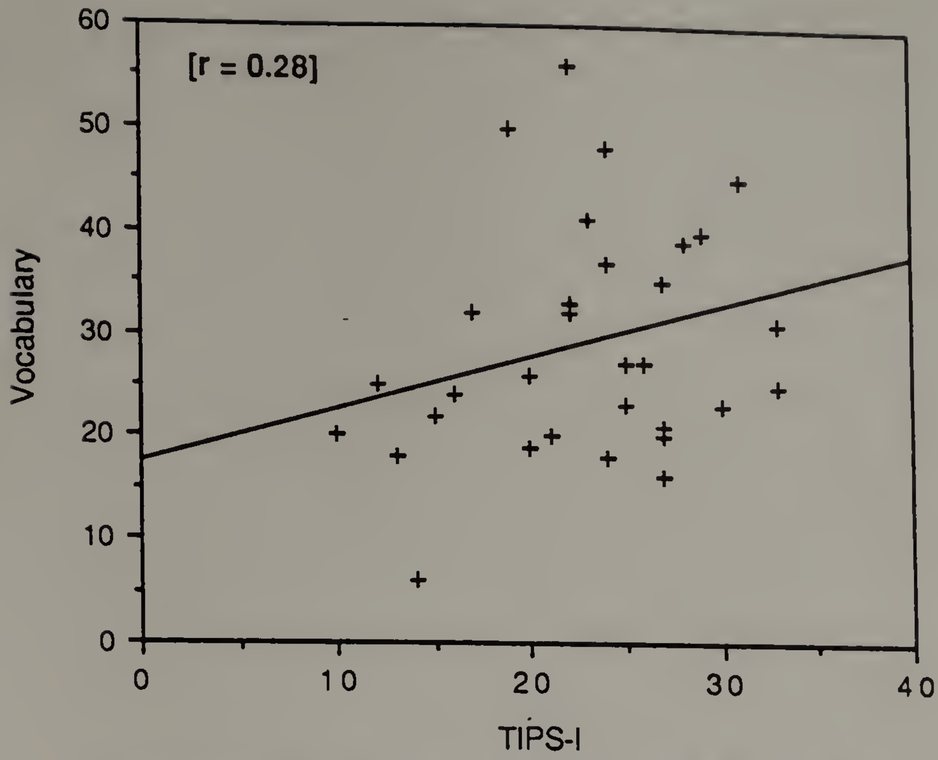


FIGURE 19. Composite Sample B: Scatter Diagram of TIPS-I vs. Vocabulary Scores

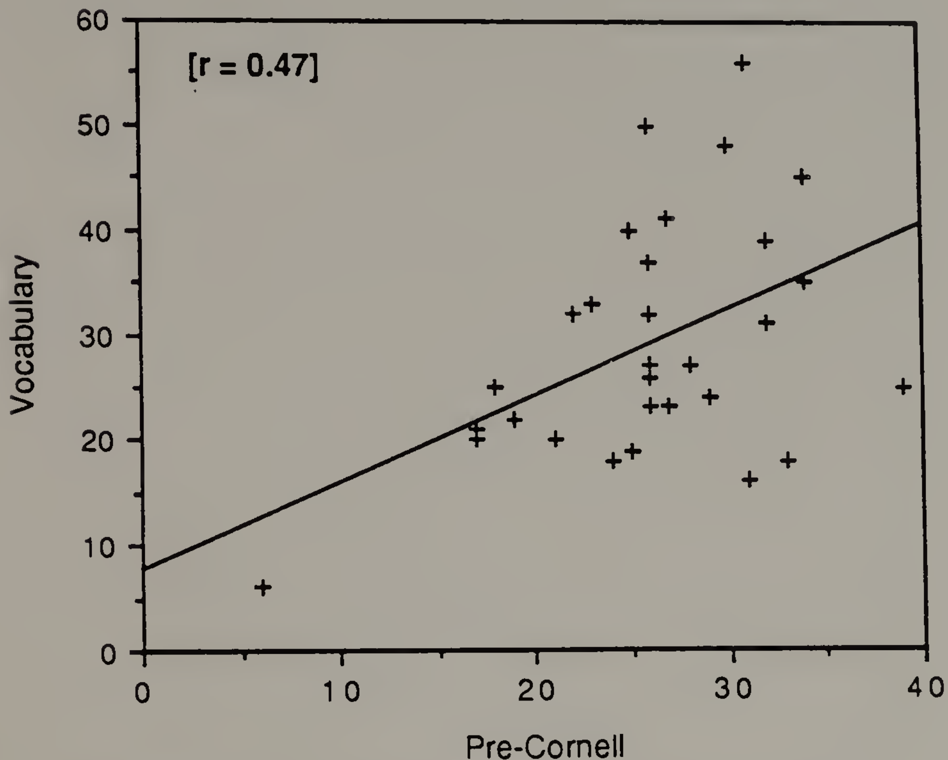


FIGURE 20. Composite Sample B: Scatter Diagram of Pre-Cornell vs. Vocabulary Scores

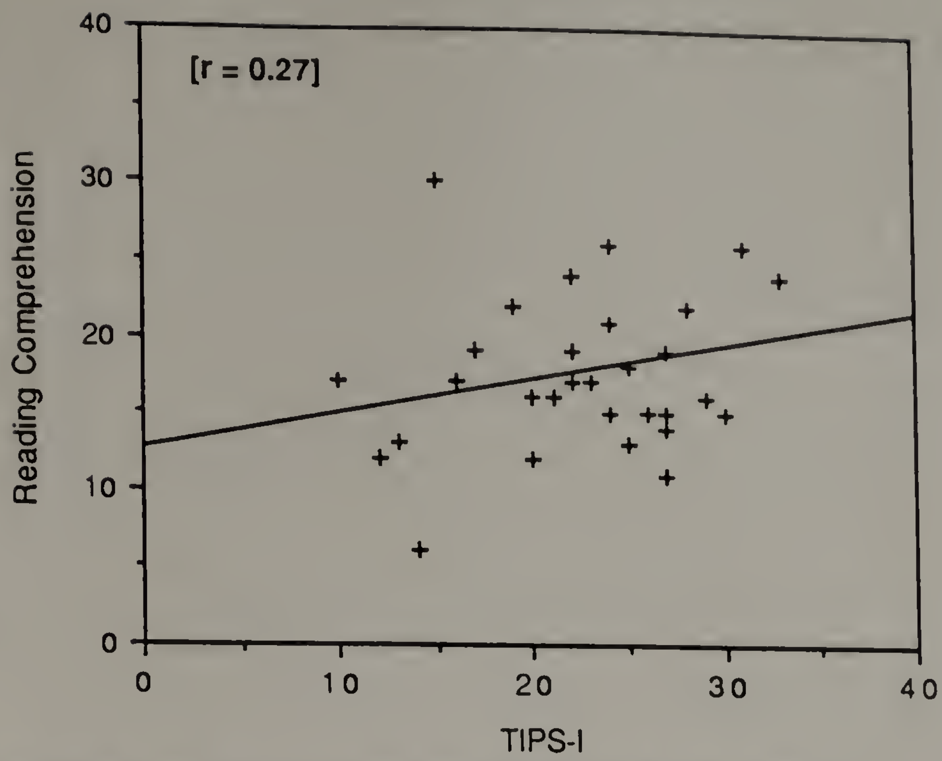


FIGURE 21. Composite Sample B: Scatter Diagram of TIPS-I vs. Reading Comprehension Scores

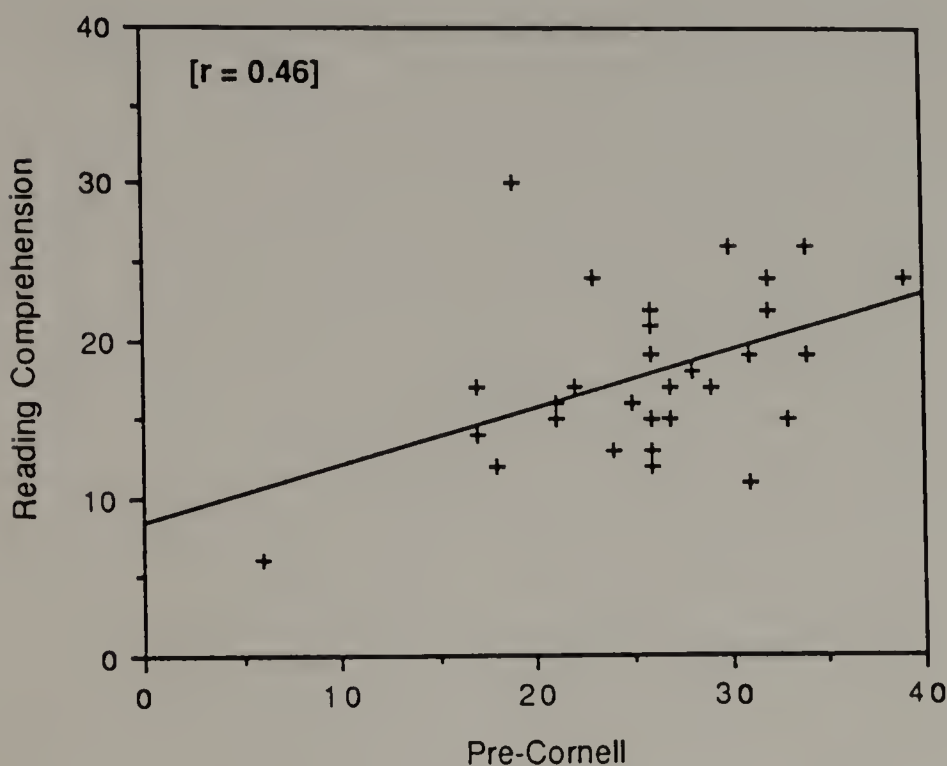


FIGURE 22. Composite Sample B: Scatter Diagram of Pre-Cornell vs. Reading Comprehension Scores

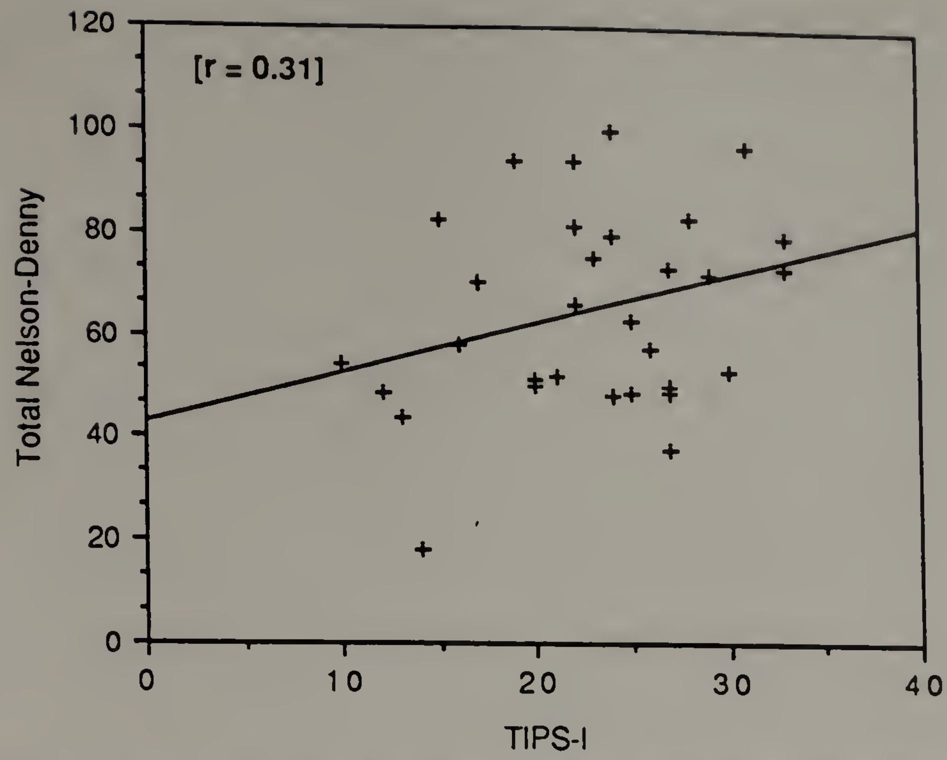


FIGURE 23. Composite Sample B: Scatter Diagram of TIPS-I vs. Total Nelson-Denny Scores

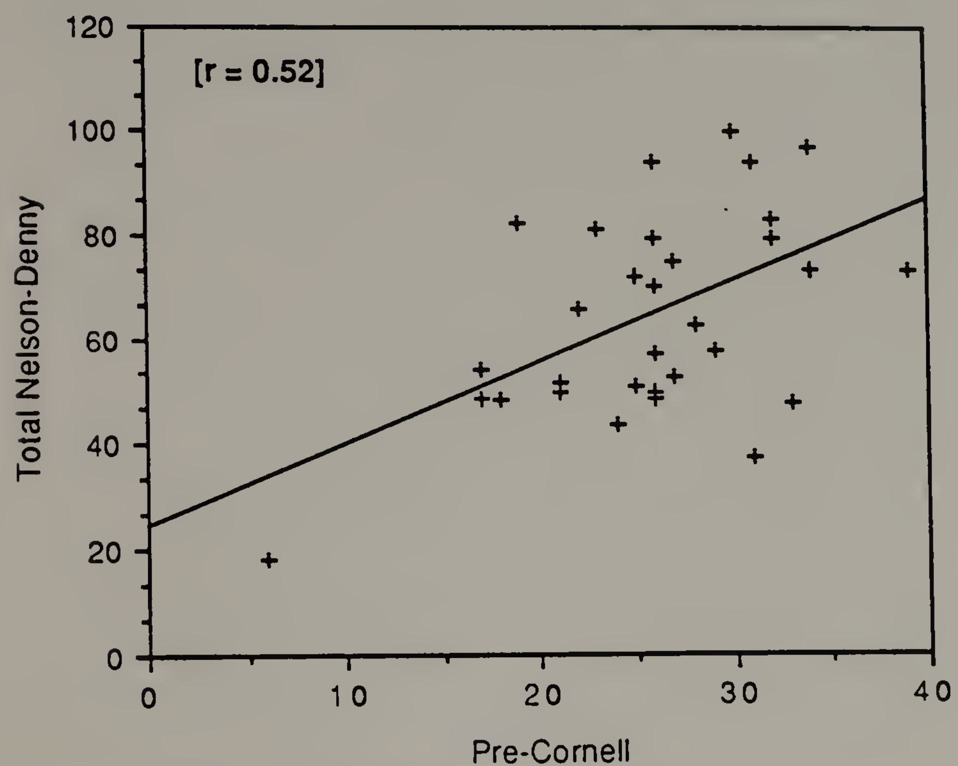


FIGURE 24. Composite Sample B: Scatter Diagram of Pre-Cornell vs. Total Nelson-Denny Scores

CHAPTER 5

DISCUSSION, CONCLUSIONS and RECOMMENDATIONS

Assessment of Problem-Solving by the TIPS

Did the microcomputer simulators effectively improve environmental problem-solving skills with community college students? This was the fundamental question investigated in the present quasi-experimental study. The Test of Integrated (science) Process Skills (Dillashaw & Okey, 1980; Burns, Okey & Wise, 1985) was selected to measure the effectiveness. Use of this test instrument parallelled an early study by Rivers & Vockell (1987).

The statistical analysis for Hypothesis I (Chapter 4) indicated there was a significant improvement in the TIPS scores for the experimental group ($\overline{X}_{gain}$= +3.03, $t_{paired\text{-}sample}$ = +4.42). This gain was achieved within five weeks of exposure to the simulations. Performance by the control group on the TIPS remained constant ($\overline{X}_{gain}$= +0.2, $t_{paired\text{-}sample}$ = +0.19) after four months. The improvement in the experimental group was significantly higher than that of the control. This was further verified by comparison of gain scores on parallel questions in TIPS-I and TIPS-II for both groups (Control: $\overline{X}_{gain\ parallel}$ = +0.54, $t_{paired\text{-}sample}$ =

+0.59 | Experimental: $\overline{X}_{gain\ parallel} = +2.62$, $t_{paired\text{-}sample} = +3.50$ [Table 2]).

The null hypothesis (Hypothesis I) was rejected in favor of its alternate for the following reasons. First, the control and experimental groups were initially representative of each other in science process skills (Sub-hypothesis Ia). Second, the experimental group significantly improved on the TIPS compared to the control group (Sub-hypothesis Ib & Ic). Environmental problem-solving skills significantly improved with community college students given the opportunity to use microcomputer simulations.

The basis for this decision laid not only with the statistical results but the validity of the TIPS instrument as well. Dillashaw, *et al.* (1980) and Burns, *et al.* (1985) designed the TIPS-I and TIPS-II to reference a specific set of objectives which focused upon scientific problem-solving. Therefore the test had construct validity. The TIPS also had content validity, because it examined problem-solving skills within the framework of the scientific method (Appendix E). Such investigative skills are needed by environmental science students (Volk, 1984; Volk, Hungerford & Tomera, 1984; UNESCO-UNEP, 1984; Hammerman & Voelker, 1987). Burns, *et al.* (1985) reported that both tests have a high Cronbach's coefficient α test reliability and identical difficulty indices (0.53).

The mean gains scores on the TIPS for the experimental group ($\overline{X}_{gain} = +3.03$, S.D. = ±4.0) exceeded those reported in the parallel study

($\overline{X}_{gain} = +1.55$, S.D. = ± 5.18) by Rivers & Vockell (1987). Grade level could partially account for the differences. This study was conducted with community college students; whereas, the parallel study examined high school students. The more critical difference, however, might have been the intellectual development of the two groups. Community college students are mainly transitional reasoners, but closer to a formal operational level than their counterparts (Appendix M). This distinction could also explain the significant improvement in problem-solving after five weeks. The parallel study reported improvement after seven months.

Assessment of the Ability to Expand Problem-Solving Skills

A primary goal of science education is to facilitate problem-solving heuristics (Padilla, *et al.*, 1983; Yap & Yeany, 1988). Its purpose is to help the students discipline their logical thought and build conceptual models which can be applied to new situations. Problem-solving is considered to be part of a larger affective domain: critical thinking (Baron, 1987). The Cornell Critical Thinking Test was used, therefore, to assess if science problem-solving skills were expanded after simulator use. Results from this study initially indicated expansion did not occur. But Rivers & Vockell (1987) also reported inconclusive findings in critical thinking improvement, as measured by the Watson-Glaser Critical Thinking Appraisal. At this juncture, there were several possible explanations which had to be explored.

The correlation between the Cornell Critical Thinking Test and the TIPS scores suggested the possibility of a Type II error (acceptance of a

false null hypothesis). Since there was a moderately positive correlation between the two assessments in Composite A, similar correlations were expected in the experimental and control groups. But the correlations in the comparative groups were considerably weaker (Table 12). On the other hand, gain score correlations were about equal in the comparative groups (Control r = 0.38; Experimental r = 0.34). Several factors could have influenced these correlations.

First, the Pearson-r is highly affected by sample size. A moderate correlation in a small sample could yield a much higher correlation in a larger sample (Burroughs, 1971). This mathematical relationship was also observed when the confidence levels were set. The lowest Pearson-r value for 95% confidence decreases with sample size (Control [n=24] = 0.41; Experimental [n=34] = 0.34; Composite A [n=86] = 0.21). Such instability partially explained the low correlation between the raw scores in the experimental group (r = 0.29) as compared to those of Composite A (r = 0.50). In contrast, the pretest correlation was higher for the control group (r = 0.75) than for Composite A, even though the means were about equal. Another aspect which could have affected stability was the sample size. The samples studied were small considering the total population of community college students. Small samples are typically subject to a restriction of the range (Burroughs, 1971).

Second, the level of improvement could be related to the initial percentile scores. Based upon data from Composite A (r = 0.50), there existed a 25% [r^2] common variance between the Cornell-Z and TIPS. This implied that 75% of the test items were specific for each test. These

values remained relatively constant despite refinement of the Cornell test items. The mean score on the Cornell pretest for the experimental group ($\overline{X}$ = 28.44) was higher than that found in either the control ($\overline{X}$ = 25.54) or Composite A ($\overline{X}$ = 25.94). Furthermore, the median was highest in the experimental group between testing for both the Cornell pretest and posttest, and the range narrowed (Table 5). Because the experimental group began at a higher level (mean, median, and percentile) any improvement would have been more difficult for this group to achieve than for the control.

For these reasons, the correlation results were suspicious and not used as the sole criterion to accept or reject the null statement for Hypothesis II. Therefore, Hypothesis II was left unresolved. Susequently, the test instrument needed to be investigated for external biases. The third hypothesis tested for one such bias: reading level.

Critical thinking is considered a very complex psychometric to assess. Leaders in the field still hold diverse positions as to its exact nature (Paul, 1984; Baron, 1987; Ennis, 1987; Sternberg, 1987). This overshadows the issue of content validity for any test instrument about general critical thinking. The constructs listed in Table 15 (Walsh & Paul, 1985) are not discrete due to some interdependence, Kuder-Richardson-21 = 0.77 (Ennis, *et al.*, 1985). The individual researcher needs to decide what constitutes critical thinking, and how it is to be evaluated. Table 8 compares similar thinking skills between the TIPS, Cornell, and Watson-Glaser tests. Scientific problem-solving skills are

addressed in the three instruments, but the TIPS is most specific for these skills.

Considering the range of constructs within the domain of critical thinking, any treatment trying to enhance problem-solving should focus on specific skills (Baron, 1987). The skills focused upon in the simulators were successfully evaluated by the TIPS, and yet not by the Cornell test. Factors that could have influenced the outcome on the Cornell are as follows: (1) test difficulty, (2) sensitivity to desired constructs, (3) length of exposure to treatment, (4) reading level, (5) use of heterogeneous intact groups, and (6) stage of mental development.

TABLE 15. Critical Thinking Skills Assessed by the California and Connecticut Testing Programs†

Compare Similarities & Differences	Identify Central Issues or Problems
Distinguish Among Fact, Opinion, and Reasoned Judgment	Recognize a Bias, Emotional Factors, Propaganda, and Semantic Slanting
Recognize Stereotypes & Cliches	Recognize Different Value Orientations & Idfferent Ideologies
Determine Which Information is Relevant	Recognize the Adequacy of Data
Check Consistency	Formulate Appropriate Questions
Predict Probable Consequences	Identify Unstated Assumptions
Identify Conclusions	Identify Reasons
Identify Appropirate Questions to Ask, Given the Situation	Determine Credibility of Source Information
Determine Relevance	Infer & Judge Deductive Validity
Predict Possible Consequences	Deduce & Judge Deductive Validity

† taken from Ennis,R., Millman, J. and T. Tomko (1985)

The Watson-Glaser Critical Thinking Appraisal was designed for grade nine through adult (Baron & Sternberg, 1987). In comparison, the Cornell Critical Thinking Test Level-Z was written for advanced high school and college students (Ennis, *et al.*, 1985). The Waston-Glaser and the Cornell Level-Z were reported to have a high correlation (r = 0.79 [Ennis, *et al.*, 1985]) with some common constructs. Selection of the Cornell over the Watson-Glaser was based upon test item construction and content validity for environmental science students. A major difference between tests was the type of answers required. The Watson-Glaser used a scale of preference; whereas, the Cornell-Z had discrete answers. Moreover, the sensitivity of these instruments for assessing scientific problem-solving expansion may only be resolved after additional large scale testing.

The length of exposure to treatment by the simulators was different in the two studies. River & Vockell (1987) provided seven simulator packages over the course of seven months for high school students. The present study used three packages for five weeks. Due to the course syllabus and the college calendar, assignment of the simulator packages and testing occurred during the second half of the spring semester. The control group did not show improvement on the Cornell after four months.

Correlations were made between the TIPS and Cornell tests with the components of the Nelson-Denny reading scores (Table 13 & 14). These indicate a significant reading bias against community college students when assessed by the Cornell Level-Z. The mean reading level

for Composite Sample B was grade 12.3 with a standard deviation of ± 2.2 grade levels. A frequency distribution of grade levels (Figure 18) shows that the sample has a range from grade 6 through 15 with a bimodal distribution at grades 10 and 13. The Cornell Level-Z was constructed for a higher reading level than the Watson-Glaser. This fact, when coupled to the reality of heterogeneous reading levels within community college classes, also helps to partially explain the posttest scores. Another possible influence was that the same form was used for the pretest and posttest (Cornell-Z), since an alternate was not available. Because of this, students may not have been as careful to re-read the paragraphs on the posttest as they were on the pretest.

A final factor to consider is the stage of mental development of community college students. It was previously cited that 40% of college students today are not formal reasoners (Lawson, 1980; Tobin & Capie, 1981; Schermerhorn, *et al.*, 1982; Thomas & Grouws, 1984; Perry,*et al.*, 1986; Yeany, 1986). Results from the Arlin Test of Formal Reasoning, given at Mattatuck Community College (spring 1989), indicated an even greater percentage of such reasoners (Appendix M). One aspect of formal reasoning is logic. Padilla, *et al.* (1983) reported a substantial correlation between the TIPS and the Test of Logical Thinking (r = 0.73). These researchers implied that an improvement in problem-solving should help develop logical thinking. But would the reverse hold true? Students with greater formal thinking abilities should be able to grasp problem-solving more easily than non-formal reasoners. However, students do not necessarily improve in all abilities simultaneously. Yap & Yeany (1988) validated that there exists hierarchial relationships among

Piagetian cognitive modes and integrated science process skills. This non-uniform development helps to explain how the experimental group did not improve as predicted.

This researcher assumed that community college students would solve scientific problems in the following sequence: identify variables, state hypotheses, design experiments, and formulate conclusions. The same sequence is listed for the TIPS (Table 8). Yap & Yeany (1988) derived different sequences used by concrete operational and transitional operational reasoners. For example, concrete operational students need to master designing experiments before they can identify and operationally define variables. Transitional operational students need to understand proportional reasoning, probability, and experimental design, before they can identify and operationally define variables, identify hypotheses, and interpret data and graphs. The author has put the above hierarchy in chart form to assist the reader (Figure 25).

This hierarchy can be applied to the data on the mean gain scores for the TIPS (Table 11). There was a higher mean gain on questions related to experimental design than subsections on identifying and defining variables. Under the concrete and transitional hierarchies, designing experiments and operationally defining variables were prerequisites to identifying variables. Designing experiments was also a prerequisite to formulating hypotheses, and to interpreting data and graphs. The mean gain scores indicated that the experimental group had developed beyond designing experiments. This group improved in formulating hypotheses and operationally defining variables. This kind of

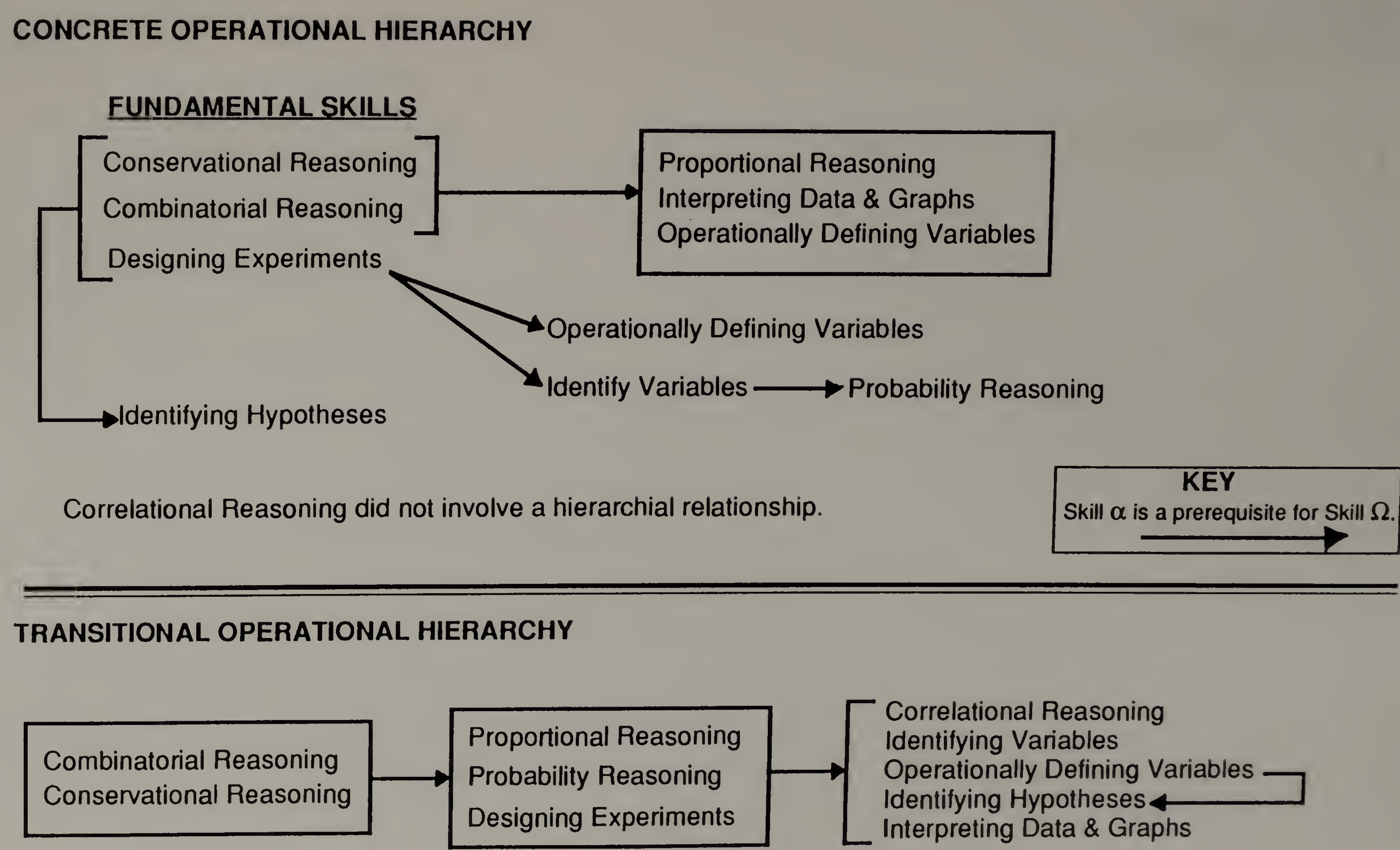


FIGURE 25. Hierarchial Relationships of Problem-Solving Skills (Yap & Yeany, 1988) in Chart Form

improvement in causal or dynamic hierarchy (Yap & Yeany, 1988) took place within the five weeks of the experiment. In contrast, the control group did not gain as much after four months. The other skills measured on the TIPS and Cornell tests may have required more time to develop than allowed in this study. Application of these higher level skills may also take longer to process than time permits on an examination.

Conclusions

Environmental education is moving beyond the acquisition of declarative knowledge. It needs to evaluate pedagogical methods which enhance problem-solving, attitude formation, and activism. This study was designed to determine if microcomputer simulators could effectively stimulate environmental problem-solving with community college students. Furthermore, it measured the improvement in problem-solving skills.

Karplus adapted Piagetian theory into a learning cycle which is composed of three phases (Schermerhorn, *et al.*, 1982): (1) exploration, (2) self-regulation or concept invention (Renner, *et al.*, 1988), and (3) application or expansion (Purser & Renner, 1983; Renner, *et al.*, 1988).

Students were presented with simulator modules in a learning cycle situation. Each module pretest indicated that learning declarative knowledge did not necessitate a functional understanding of

environmental problems. The simulators allowed students to concretely explore the environmental problems. Dispersed throughout this exploration were informal discussions within the lab groups. Only during the first package did the instructor hold a formal discussion. This discussion helped to summarize the first part of *Lake Study* by gathering the class data. From the larger data pool, students were encouraged to use divergent thinking and to develop a logical hypothesis. These hypotheses were tested in the second part of *Lake Study*. Renner, *et al.* (1988) recommended that discussions follow data collection to allow the next phase of the learning cycle: concept invention. Teacher-centered discussions were not carried out after the first package. This encouraged the lab groups to work as a team and discuss the problems together without expert thought. If the exploration and expansion phases were good, then the concept invention through formal discussion could be skipped (Renner, *et al.*, 1988).

One future recommendation is that the packages be punctuated by formal discussions. Such discussions will help in the following ways: (1) to focus student problem-solving, (2) to summarize group thinking, (3) to facilitate concept invention, and (4) to alleviate the anxiety of the more field-dependent learners. A follow-up discussion could also be used to challenge students' environmental decision making.

Results from the Test of Integrated (science) Process Skills indicated that simulators could stimulate significant improvement in problem-solving. Evidence for this improvement was obtained from gains in both total scores and subsection scores. Data from the TIPS

indicated that the first and second phase of the learning cycle were interactively accomplished with the simulators. The transitional reasoner could be given a concrete experience to explore within a simulator. From this activity, the student would develop a mental structure which could possibly be expanded later. Thus, simulators can help improve environmental problem-solving skills.

Whether or not students could expand these problem-solving skills became more difficult to evaluate than anticipated. The data generated from the Cornell Critical Thinking Test Level-Z was subject to many unexpected external influences. Reading level was determined to be a bias with the population studied. Therefore, the possibility that students could expand problem-solving skills after use of computer simulators should not be ruled out. Problem-solving within the context of critical thinking is a very complex psychometric to assess. It is subject to an amorphous content, length of exposure to treatment, reading level, test sensitivity, stage of mental development, and hierarchial relationships of discrete reasoning skills. Because of all these influences, the testing done to assess problem-solving expansion was considered inconclusive.

There were many other problem-solving skills not measured by either the TIPS or Cornell tests. Subjective improvement of these skills was revealed in the subsequent laboratory reports submitted for each simulator module. It was evident that more concept invention occurred in the experimental group than what typically happens a traditional lecture. The simulators helped students in several ways: (1) they learned content within the framework of an actual research problem; (2) they came to

understand the limits of laboratory tests; (3) they isolated and extracted pertinent information from research material; (4) they formulated concepts in small group discussions; (5) they began to recognize the limitations of predictions based upon computerized models; and (6) they developed a metacognitive ability to weigh trade-offs and devise financially and environmentally successful strategies for management and survival. The successive laboratory reports showed an overall improvement in these skills. The students became better problem-solvers with each simulator module. They were able to investigate and resolve the environmental problems given progressively less structure. The students became more field-independent.

This study yielded other information about the use of microcomputer simulators in environmental education. The following generalizations are taken from instructor anecdotes and student comments on the course evaluation: (1) students had to adjust to learning from computers; (2) students' confidence increased and anxiety decreased as computer exposure time increased [as one seventy-six year old woman stated, "...I've never used a computer yet, but I'm willing to give it a try.."]; (3) students felt the simulators helped them to better understand the concepts better [another student wrote, "...reading and listening do not imply thinking and ability to work through problems.."]; (4) they liked the opportunity for active learning; (5) they found that a team approach allowed for a wider range of knowledge, opinions, and ideas; (6) most students agreed the best team size was three; (7) many students would take advantage of optional simulators and tutorials if available; (8) they wanted more flexibility in the program structure to allow branching ahead; (9)

students requested computer use dispersed throughout the semester rather than several weeks together; (10) they asked for software to be available on loan for home study. The interest and interaction level of the students intensified as the study proceeded. Students were spending more time in the laboratory in addition to normal class time. They also informally discussed related environmental problems from their own communities.

Establishing microcomputer simulators as part of an environmental science course required cooperation from several directions. Fortunately, the college administration and the science faculty were supportive. Testing required the cooperation of several instructors. Precious laboratory space had to be scheduled to set up the borrowed equipment. Because of all the logistics, the simulator packages were run consecutively. These situations will be permanently resolved as the science laboratories utilize more microcomputer simulations.

Although the samples presented within this study are relatively small and limited to two classes, they are representative of Mattatuck Community College as a whole. In light of this fact, and assuming that the student body at Mattatuck is typical of the national community college student population, some inferences can be extended to a broader context. This study determined that microcomputer simulators can be effective in developing environmental problem-solving heuristics with community college students. Generally, community college science instructors are limited to relatively simple laboratory procedures. These procedures have to be accomplished in a two-hour laboratory session by novice science students. This study demonstrates that microcomputer simulators

provide a viable option. Perhaps simulators are even more effective than traditional instruction in developing problem-solving skills. Allowing students to repeatedly tinker with an ecosystem stimulates a kind of active learning that extends far beyond traditional lectures and reading assignments. The environmental simulator offers the opportunity to present content, while at the same time enhances cognitive skills and fosters mental development.

If the improvements reported in this study were possible with environmental students at community colleges, could other science courses also benefit from microcomputer simulations? A pilot study group was set up prior to this investigation using a small general biology class (Appendix L). The results indicated an improvement in problem-solving ability even when simulating entirely different concepts (*e.g.*, osmotic pressure, genetics, and enzyme kinetics).

The need to incorporate computers into science education for the two-year college was a recommendation by the National Science Board to the National Science Foundation in the report, *Undergraduate Science, Mathematics and Engineering Education.* Another growing concern is the development of higher order thinking skills in the nation's schools. On a state level, Connecticut has already mandated critical thinking assessment in grades K-12. Teacher and program effectiveness are being linked to the standardized test results. Whether or not this testing will extend into college level has yet to be decided by the Connecticut State Board of Higher Education. *The New York Times* recently reported the

American College Testing Program will, for the first time, begin to assess student understanding of scientific concepts (*Providence Journal*, 1989).

Recommendations for Further Study

1. Establish a true experimental design, instead of a quasi-experimental design, with one group using the microcomputer simulator and the other a controlled instructional format, such as an auto-tutorial module.

2 Include in the experimental design an additional method to quantify subjective responses in laboratory reports in addition to objective tests.

3. Assess for gains in reasoning level along with scientific problem-solving by using either the Group Assessment of Logical Thinking (GALT) (Yap & Yeany, 1988) or the Science Reasoning Tasks (SRT) (Renner, *et al.*, 1988), along with the Test of Integrated (science) Process Skills (TIPS). Both the GALT and SRT may prove to be more sensitive to gains in scientific reasoning and ability to expand problem-solving skills than the Cornell Critical Thinking Level-Z. They may also be less biased by reading ability.

4. Increase the time interval between pretest and posttest on the outcome assessments.

5. Include some activity to improve prediction skills as part of the learning cycle (Lavoie & Good, 1988).

APPENDICES

APPENDIX A

Human Subjects Consent Form

15 January 1988

TO: Students of Biology 110/120 Environmental Science & Biology
103 General Biology

FR: Joseph V. Faryniarz, Doctoral Student, School of Education,
University of Massachusetts-Amherst

RE: Participation in Research Study - PARTICIPATION CONSENT FORM

Throughout this semester, I have stressed the idea that what we know about science is the result of investigation. I come to you now, not as your professor but rather as a fellow student. I need your help to carry out a research study that should further our knowledge about environmental education with community college students.

Last year, I began using microcomputer simulators in both Environmental Science and General Biology. The educational research literature indicates simulators could have a positive impact on your learning experiences. So I tried a few in my courses. Students then suggested that the opportunity to use the simulators be developed more. After further research, study, and thought I have designed several interesting modules which utilize some of the available simulators on the market. These will be part of the ordinary coursework, and will be included as part of your course evaluation.

My research examines if simulators will improve your scientific problem-solving skills. To do this, I am asking you to take two short objective tests which will be kept confidential. The test will not influence your course grade in any manner. After the second testing is completed I'll be happy to discuss your particular scores with you privately. The two tests are the Test for Integrated Process Skills and the Cornell Critical

Thinking Test Level-Z. Everything will all be done during the regular lecture/lab time.

As a faculty member at Mattatuck Community College, I have access to your reading placement scores in the admissions office. However, I think it is proper for me to officially request your permission to obtain these scores. Again, please understand that these and all other scores will be kept in strict confidence. Your scores will be coded to a private student number.

You are not under any obligation to take part in this study, nor will your course grade be influenced by your decision. Should you decide at any time during the semester to withdraw from the study you can, with no influence on your course grade. The work with the simulators is part of the curriculum; therefore, it is mandatory. My request is for your permission to take the two special tests, and obtain your reading score.

I want to find out if computer simulators can help to improve your problem-solving skills. Secondly, I want to determine if these skills can be later expanded. The data collected will be statistically analyzed. Then, I will try to develop some conclusions about the advantages and disadvantages of using environmental simulators with community college students. The information gained by this study will be used in my doctoral dissertation and possibly in workshops for other instructors.

To improve science education, there needs to be an opportunity for investigation and research. I hope you will agree to take part in my study and share in an ongoing research project.

Thank you for your time and cooperation.

PARTICIPANT CONSENT FORM

I, ____, have read the above
(print name)

statement and agree to the conditions stated therein.

____________________________________ Date: ________________
(Signature of Participant)

APPENDIX B

Lake Study Simulator Module

Introduction

During the next several class meetings you will have the opportunity to investigate water pollution. It is impossible to provide an entire river or lake in the laboratory for your study. Moreover, there is not enough time in a single semester to make each of you proficient in the needed laboratory and field techniques to carry out such investigations. In view of these restraints, your investigations will be done with a microcomputer simulator.

Beginning next week, the class will be divided into research teams. Each team will be provided an Apple IIe computer and software developed by Project SERAPHIM under the National Science Foundation. This software is specifically written for introductory non-major science students studying environmental pollution. *Lake Study* (Part 1) delves into trying to find out what is killing fish at a hatchery. *WAQUAL* (Part 2) gives you some experience at running a wastewater treatment plant. This will be a challenge, since you will have to run the plant and try to satisfy several factions. These include a beach of angry bathers who want clean water, and the city council who do not want cost over-runs. Both simulators are enjoyable and interesting experiences. The simulators are enjoyable, because students will not get discouraged by laboratory techniques. The simulators are interesting, because you will actively come to understand how science works.

Computer time and lab time are valuable commodities, so use them wisely!!! Be sure to read over the attached documentation for each simulator before arriving. I realize that many students have complicated schedules which curtail outside assignments, hence you will be given ample class time to complete the computer aspect of these assignments. However, I expect students immediately to begin work with the simulators and not waste time reading over this handout, which should be done beforehand.

There is also a need for independent reading in your textbook to help you understand basic concepts. Be sure to understand the following concepts when preparing for the first lab session:

- scientific method - handout
- abiotic vs. biotic aquatic ecosystem factors
- non-point vs. point pollution sources
- lentic aquatic systems vs. lotic aquatic systems
- characteristics of lake zones: littoral, limnetic, profundal, epilimnion, hypolimnion
- effect of temperatures on dissolved oxygen
- strategy behind a bioassay, LD-50 (second lab discussion)

Objectives

By the end of this computer simulator the student will be able to:

1. Apply the scientific method to an environmental problem.

2. Observe an environmental situation and develop a statement of problem.

3. Formulate testable hypotheses based upon the stated problem.

4. Identify the variables which exist within the stated problem.

5. Understand the nature of the research tools available, and the kind of data that each tool can provide, and its relevancy to the stated problem.

6. Devise an experimental strategy to test student hypotheses with the research tools available.

7. Isolate and extract relevant information which can be applied in the scientific method to test the hypotheses.

8. Analyze and integrate experimental data, tested hypotheses, and research literature, to resolve an environmental problem.

9. Interpret scientific data from tables and graphs.

10. Realize that scientific investigations have limitations and cannot always decisively resolve a specific environmental problem.

11. Explain, in a formal laboratory report, how the information gained via the computer simulator was used to arrive at a specific conclusion or position regarding the environmental problem investigated.

APPENDIX C

Wastewater Quality Analysis (WAQUAL) Simulator Module

Introduction

During this simulator, you will experience the challenge of managing a wastewater treatment plant. The opportunity should give you a better understanding of the inter-relationships between the abiotic and biotic factors associated with the river and plant ecosystem. Along with these, you must also deal with decisions based on economics and societal pressures. Such an integrated approach allows you to mentally build a conceptual model. From this model, you should then be able to make inferences about the plant's operation.

As with *Lake Study*, the application of the scientific method is necessary to explore the cause and effect relationships between all of the parameters in the simulator. There is still a need to analyze these relationships by systematically making choices over control and variable factors.

The introduction to both aquatic pollution simulators was covered in the *Lake Study* simulator module. There is still a need for independent textbook reading. Prepare for this module by reading about the following concepts:

- scientific method - handout
- abiotic vs. biotic aquatic ecosystem factors
- non-point vs. point pollution sources
- lentic aquatic systems vs. lotic aquatic systems
- effect of temperature on dissolved oxygen
- difference between primary, seconday, and tertiary wastewater treatment
- effect of nutrient loading on: river septic/recovery zone distance, DO, and BOD

Objectives

By the end of this computer simulator the student should be able to:

1. Apply the scientific method to an environmental problem.
2. Observe an environmental situation and develop a statement of problem.
3. Formulate testable hypotheses based upon the stated problem.
4. Identify the variables which exist within the stated problem.
5. Comprehend the multifaceted problems associated with operating a wastewater treatment plant which must satisfy environmental, economic, and societal standards.
6. Understand the relationship between each type of wastewater treatment, its effectiveness specifically on BOD, its relative cost, and impact on river ecology
7. Devise a strategy to successfully manage a wastewater treatment plant over the course of four seasons.
8. Analyze and integrate experimental data and tested hypotheses in an effort to resolve an environmental problem.
9. Interpret scientific data from tables and graphs.
10. Isolate and extract relevant information which can be applied in the scientific method to test hypotheses on how to best run the plant.
11. Realize that compliance under any environmental mandate requires weighing trade-offs (impacts) in the decision making process.
12. Explain, in a formal laboratory report, how the information gained via the computer simulator was used to arrive at a specific conclusion or position regarding the environmental problem investigated.

APPENDIX D

Natural Populations & Community Dynamics Simulator Module

Introduction

If you placed a few bacterial cells into a glass of milk and left it on the kitchen counter for even a day, you would probably return to sour milk. The milk soured due to the metabolic activities of the bacteria. However, the quick change from good to sour milk is not the work of the few original bacteria; rather, it is the work of 786,432 bacterial cells that have grown in the six hours.

Similar growth occurs in rabbits. You might start with a mating pair producing only six offspring (3 male, 3 females), but in just five generations your cage would be filled with 486 rabbits. The situation is even more dramatic with fruit flies. Start with a mating pair which lays 40+ eggs/day and after a month the result would be 20,480,000 flies!

Fortunately in natural populations, there exist many factors which mitigate the effects of such exponential population growth. Some of these factors are within the species themselves (density-independent). Others pertain to the species' physical environment (density-independent). Still other factors are the result of several species interacting in their ecosystem (community dynamics).

In this group of computer simulators you will have the opportunity to discover the various kinds of population growth and community dynamics along with their inter-related environmental factors. The advantage of using a computer simulator to learn about populations and communities is that students can transcend the complicate mathematical formulas that ecologists use to make growth projections. In other words, you will be able to think about the concepts without getting lost in the math. The computer will calculate formulas, construct table, and plot graphs at warp speed. Using this information, you should be able to build a conceptual model to understand better the theory for population growth

and community dynamics. Once again, this work will be done within the framework of the scientific method.

Objectives

By the end of this computer simulator package the student will be able to:

1. Contrast the ecological concepts of population vs. community.

2. Distinguish between exponential and sigmoid population growth.

3. Comprehend how exponential population growth rate is the outcome of biotic potential, birth rate, reproductive rate, generation time, death rate, migration, density-independent and density-dependent limiting factors.

4. Realize how an ecosystem can sustain population growth up to the carrying capacity (sigmoid growth); this capacity is determined by environmental limits, migration, density-independent, and density-dependent limiting factors.

5. Analyze population data (tables & graphs) to interpret the inter-relationships between population growth, biotic potential, carrying capacity, migration, and low-breeding density.

6. Design experiments, based upon the scientific method, to investigate characterisitic population growth and community dynamics within the framework of a microcomputer simulator,

7. Explain the effects of various environmental limiting factors and species interaction which determine community dynamics and population cycling.

8. Distinguish the effects that birth rate, death rate, and initial population size have upon community dynamics.

9. Identify several examples of inter-species or community interactions.

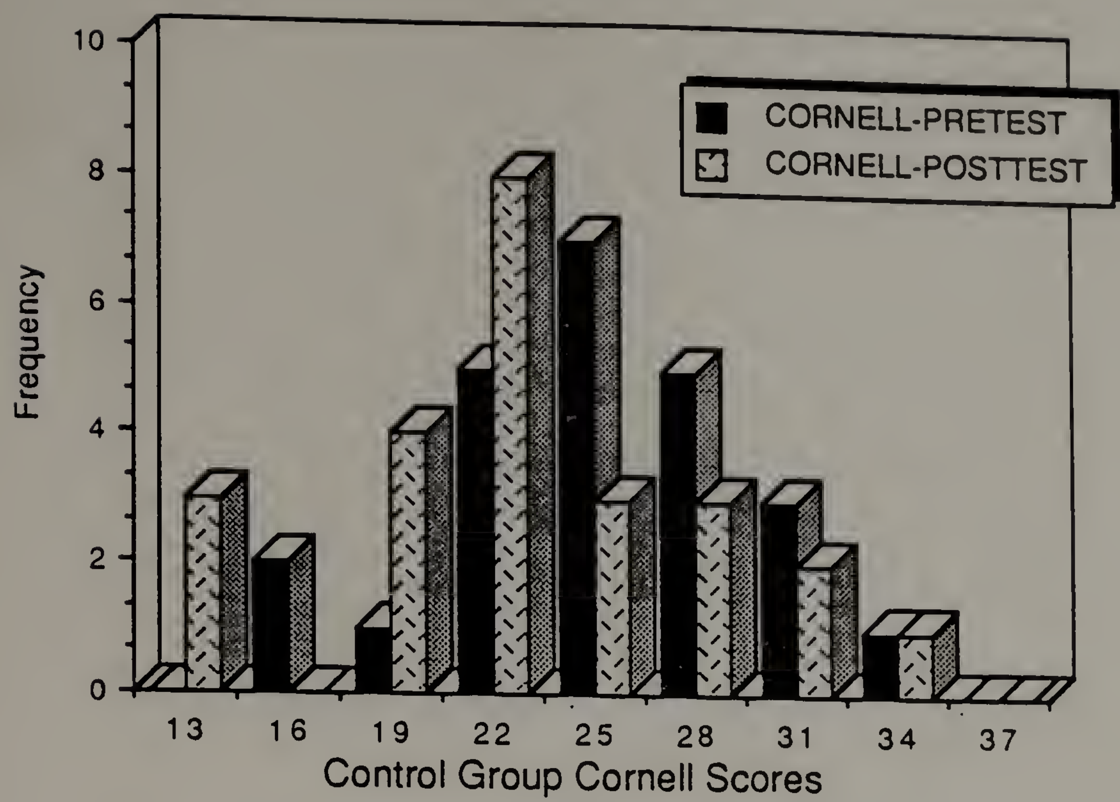
10. Utilize a microcomputer simulator to predict the outcome of a community dynamics problem.

11. Assess the effectiveness of a management strategy devised for the survival of a community by using the scientific method.

APPENDIX E

Comparison of Test Items for TIPS

List of Parallel Questions for TIPS-I & II	6, 8, 10, 11, 12, 13, 14, 15, 16, 17, 20, 21, 22, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36
List of Questions for Original Categories	
Identify Variables TIPS-I	1, 7, 14, 15, 16, 25, 26, 27, 29, 32, 34, 35
TIPS-II	1, 3, 13, 14, 15, 18, 19, 20, 30, 31, 32, 36
Identify & State Hypotheses TIPS-I	4, 8, 9, 13, 18, 21, 23, 28, 33
TIPS-II	4, 6, 8, 12, 16, 17, 27, 29, 35
Operationally Define Variables TIPS-I	2, 3, 5, 17, 19, 20
TIPS-II	2, 7, 22, 23, 26, 33
Desiging Investigations TIPS-I	10, 22, 24
TIPS-II	10, 21, 24
Interpretation of Data & Graphs TIPS-I	6, 11, 12, 30, 31, 36
TIPS-II	5, 9, 11, 25, 28, 34
List of Questions for Derived Categories TIPS I & II	
Isolate & Operationally Define Variables	14, 15, 16, 25, 26, 27, 29, 32, 34, 35,
Interpret Data Tables & Approximate Trends in Graphs/Tables	6, 30. 36
Analyze Graphs	11, 12, 31
Experimental Design	10, 17, 20, 22, 24
Formulate Hypotheses	8, 13, 21, 28, 33



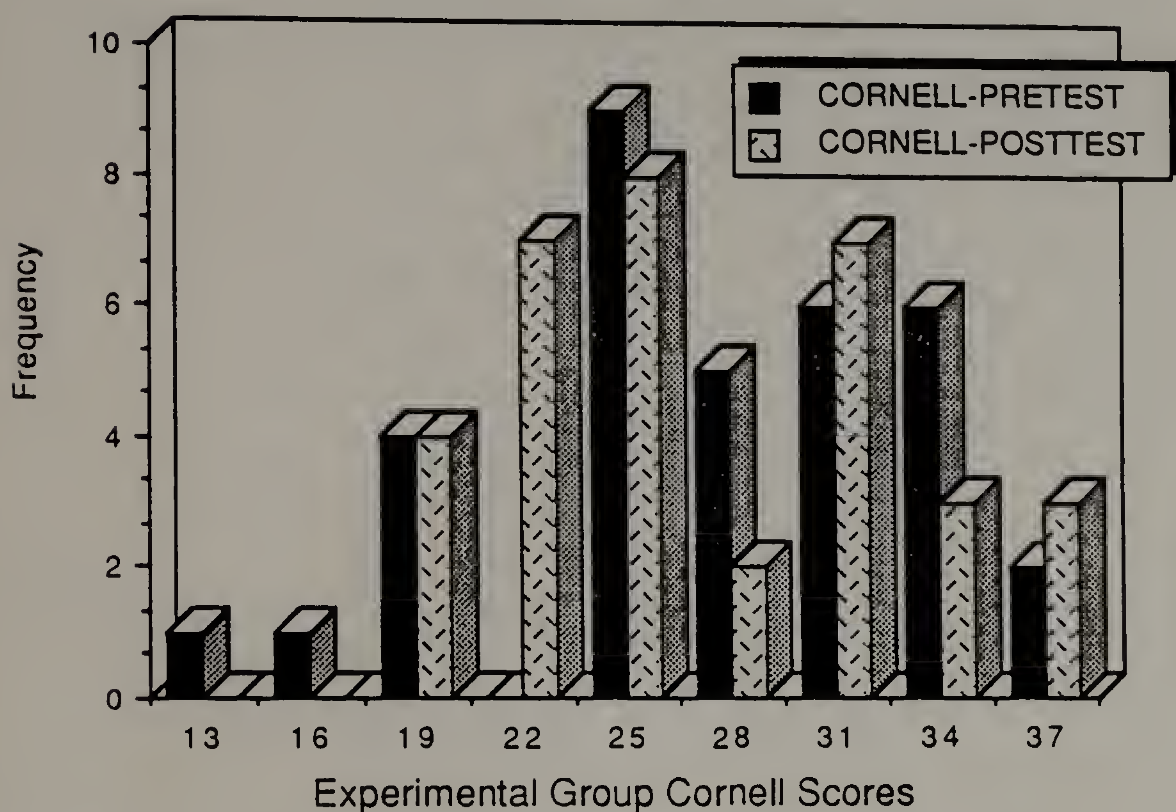
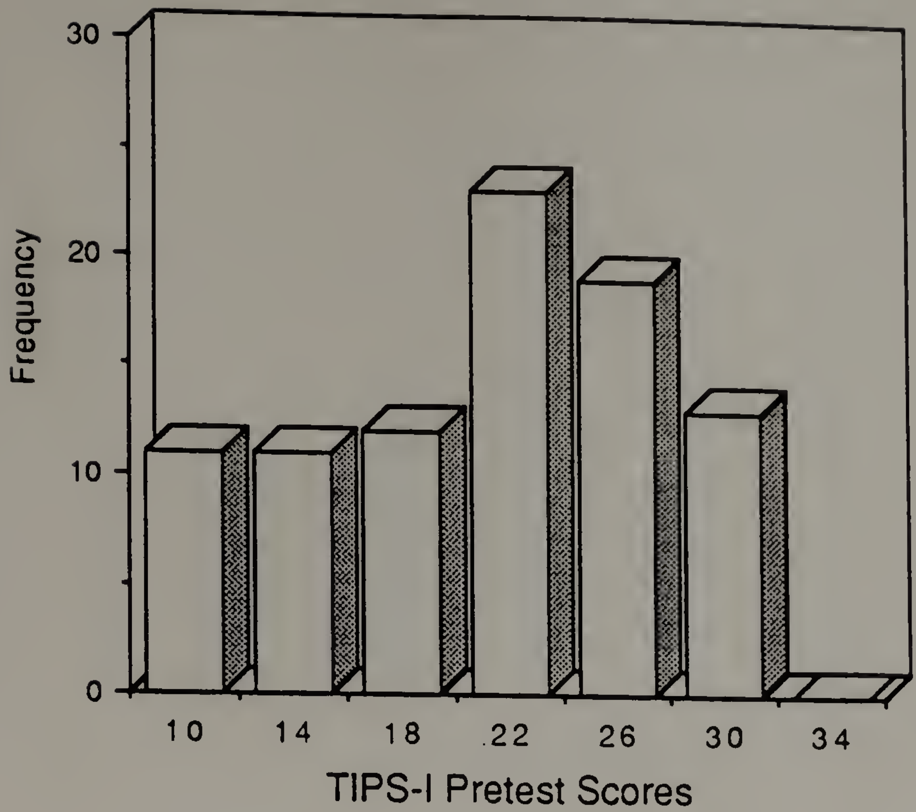


FIGURE A-1. Frequency Distribution of Cornell Level-Z Pretest/Posttest Scores for Control and Experimental Groups



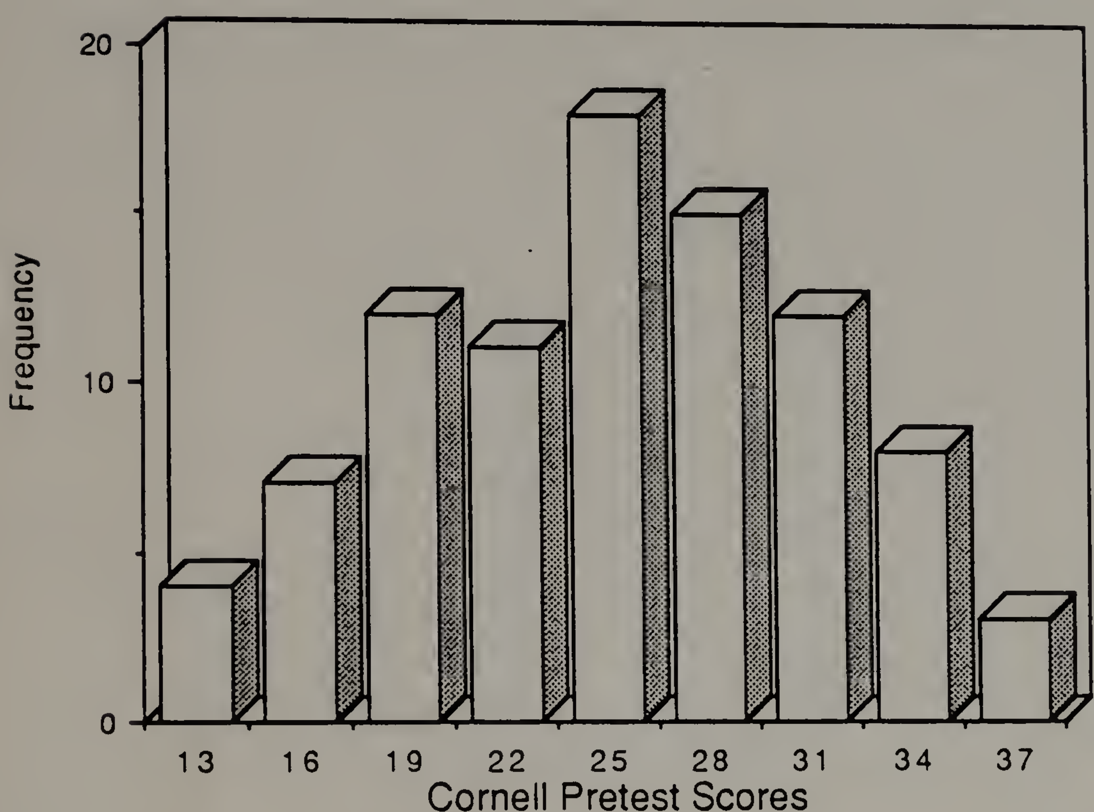


FIGURE A-2. Composite Sample A: Frequency Distribution of TIPS-I and Cornell Level-Z Scores

APPENDIX H

Comparison of Test Items for Cornell Critical Thinking Appraisal Level-Z

Original Subsections	
Deduction	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Semantics	11, 12, 13, 1,4 15, 16, 17, 18, 19, 20, 21
Credability	22, 23, 24, 25
Induction (Judging Conclusions)	26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38
Induction (Planning Experiments)	39, 40, 41, 42
Definiton & Assumption Identification	43, 44, 45, 46
Assumption Identification	47, 48, 49, 50, 51, 52
Derived Subsections for Refined Cornell	
Interpretation of Data & Draw Conclusions (not from graphs)	17, 22, 23, 29, 30
Determine Effects of Outside Outside Interference Upon Experiment	28, 34, 37
Judge the Relevance of Additional Information to Experimental Design	31, 32, 33
Reasses Conclusions Based Upon Additional Information from Repeated Experiments	26, 27, 35, 36, 38

APPENDIX I

TABLE A-1. Refined Cornell Level-Z Scores for Control and Experimental Groups, and Descriptive Statistics

Subject	CONTROL GROUP			EXPERIMENTAL GROUP		
	Pretest	Posttest	Gain	Pretest	Posttest	Gain
1	12	4	-8	9	6	-3
2	7	9	+2	9	12	+3
3	9	7	-2	6	10	+4
4	12	8	-4	5	10	+5
5	7	7	0	11	7	-4
6	6	9	+3	8	6	-2
7	12	8	-4	7	8	+1
8	7	4	-3	11	14	+3
9	10	9	-1	12	10	-2
10	10	8	-2	6	9	+3
11	11	12	+1	14	10	-4
12	7	2	-5	8	9	+1
13	8	6	-2	8	9	+1
14	11	14	+3	14	12	-2
15	11	8	-3	10	5	-5
16	12	11	-1	9	9	0
17	7	8	+1	12	11	-1
18	8	2	-6	12	9	-3
19	9	6	-3	7	9	+2
20	8	9	+1	8	6	-2
21	8	8	0	14	9	-5
22	12	11	-1	6	6	0
23	7	8	+1	12	12	0
24	10	6	-4	9	14	+5
25				13	10	-3
26				9	8	-1
27				12	13	+1
28				10	7	-3
29				14	13	-1
30				14	13	-1
31				3	5	+2
32				7	7	0
33				10	10	0
34				12	15	+3
Number of Test Items			16			
Σ Gain			-45			-11
Mean	9.20	7.67	-1.88	9.74	9.50	-0.32
S.D.	±2.93	±2.87	±2.61	±2.93	±2.70	±2.79

APPENDIX J

TABLE A-2. Composite Sample A: Refined Cornell Level-Z and TIPS-I Scores, and Descriptive Statistics

Subject	Refined Cornell	TIPS-I	Subject	Refined Cornell	TIPS-I
1	12	25	44	8	16
2	7	13	45	14	15
3	9	28	46	6	21
4	12	32	47	12	30
5	7	25	48	9	32
6	6	10	49	13	27
7	12	24	50	9	32
8	7	12	51	12	11
9	10	25	52	10	22
10	10	29	53	14	29
11	11	27	54	14	33
12	7	10	55	3	26
13	8	22	56	7	25
14	11	26	57	10	25
15	11	30	58	12	31
16	12	30	59	7	27
17	7	14	60	14	28
18	8	20	61	8	32
19	9	21	62	11	22
20	8	10	63	5	18
21	8	23	64	9	24
22	12	22	65	12	33
23	7	23	66	11	24
24	10	24	67	9	23
25	9	20	68	11	28
26	9	29	69	3	27
27	6	17	70	9	17
28	5	16	71	1	14
29	11	27	72	8	25
30	8	30	73	10	22
31	7	15	74	8	21
32	11	28	75	5	13
33	12	22	76	9	31
34	6	26	77	1	13
35	14	31	78	10	17
36	8	18	79	7	12
37	8	19	80	10	29
38	14	22	81	8	19
39	10	14	82	8	11
40	9	26	83	6	9
41	12	22	84	11	24
42	12	27	85	9	21
43	7	14	86	11	21

Number of Items	16	36
Mean	9.10	22.56
Standard Deviation	±2.80	±6.37
Pearson-r Correlation	0.45	

APPENDIX K

Environmental Microcomputer Software Reviewed

Annenburg Project, Inc.

Climate & Biomes Videodisc

Cambridge Development Laboratory,

Balance
Oh Deer
Pollute
Predation

Conduit, University of Iowa

Acid Base Titration
Compete: Plant Competition
Ecological Modeling
EVOLUT: Evolution & Natural Selection
Island Biogeography
Mark & Recapture
Population Dynamics
Population Growth
Predation
Predatio Equilibria

Educational Materials & Equipment Company

Air Pollution
Community Dynamics
Home Energy Conservation
Natural Selection
Population Concepts
Water Pollution

K. Hinze (1984)

WORLD-2

Human Resources Media, Inc.

Nuclear Power

Videodiscovery, Inc.

Biomes
Ecology
Bio Sci Videodisc
Freshwater Ecology

APPENDIX L

Pilot Study Group

This data was obtained from a General Biology class at Mattatuck Community College. The pilot study indicated that students in other science courses can benefit from the use of appropriate simulators. The group used simulators to investigate: osmotic pressure, enzyme kinetics, and genetics. Both the TIPS and Cornell assessments were given as pretest/posttests.

TABLE A-3. Descriptive and t-Test Statistics from TIPS & Cornell Level-Z Pretest/Posttest Assessments in Pilot Study Group

	TIPS			Cornell Level-Z		
Subject	Pretest	Posttest	Gain	Pretest	Posttest	Gain
1	27	28	+1	21	32	+11
2	28	32	+4	38	31	-7
3	32	29	-3	27	29	+2
4	22	31	+9	34	29	-5
5	18	29	+11	21	13	-8
6	24	34	+10	30	31	+1
7	33	27	-6	32	32	0
8	21	20	-1	23	24	+1
9	24	30	+6	28	28	0
10	23	30	+7	21	25	+4
11	28	35	+7	32	31	-1
12	27	22	-5	17	26	+9
13	17	22	+5	22	23	+1
14	14	13	-1	6	18	+12
Σ Gain			+44			+12
Mean	24.14	27.29	+3.14	25.14	26.57	+1.43
Standard Deviation	5.50	6.04		8.19	5.63	
Median	24	29		25	28.5	
Paired-Sample t-Test			+2.08			+6.07

TABLE A-4. Pearson Product-Moment Correlation Coefficients for Pilot Study Group

TEST	Pre-Cornell	POSTTEST TIP-II	POSTTEST Cornell
TIPS-I	0.59	0.52	0.78
Pre-Cornell	-	0.80	0.67
Post-Cornell	0.67	0.54	-

The pilot study group significantly improved their problem-solving skills and in their ability to expand these skill to other applications as noted by the t-test statistic in Table A-3.

APPENDIX M

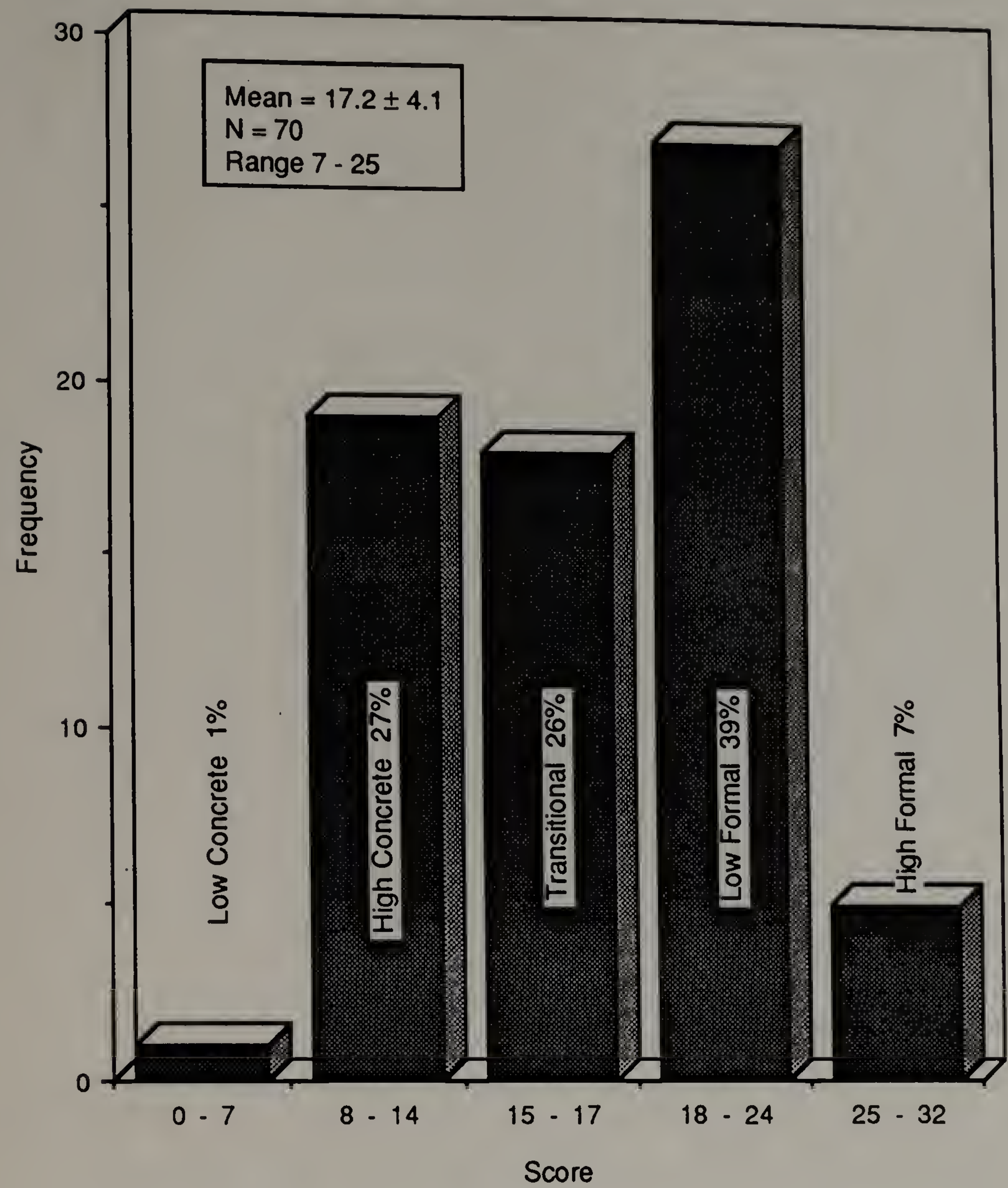


FIGURE A-3. Frequency Distribution of Arlin Test of Formal Reasoning

N.B. This testing was carried out the following year (spring 1989) with students enrolled in general biology and environmental science.

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