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Assessment of Middle School Students' Cognitive Performance on Piagetian Tasks Requiring Formal Abstract Thinking Processes

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ASSESSMENT OF MIDDLE SCHOOL STUDENTS' COGNITIVE PERFORMANCE ON PIAGETIAN TASKS REQUIRING FORMAL ABSTRACT THINKING PROCESSES

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DEDICATION

To all students labeled *unsuccessful* too early in their school career and especially those adolescents described below who are "In the Middle" ---

> *Full of energy -- not quite right*
> *Calling up friends in the middle of the night*
> *Child yesterday -- adult today*
> *How can they ever find the way?*
>
> > *Drugs, sex, divorce, crimes and woes*
> > *Boys, girls, parents, teachers, friends and foes*
> >
> > *Homework, housework, schoolwork, play, ...*
> > *Won't someone help me find the way??*
>
> *Sink or swim -- try to win*
> *Star today, failure tomorrow*
> *Is there any consistency for me to borrow?*
>
> *Please my parents, teachers and friends*
> *Is there really a God who mends?*
> *Please myself, discover my talents, find the way,*
> *Will I ever find a balance?*
>
> > *Crying for help from young and old*
> > *Trying to fit into the mold*
> > *Caught in the middle*
>
> *Child today, adult tomorrow ...*
> *Will I find joy; Will I find sorrow?*

-- by Marilyn McClaskey

CHAPTER I

THE RESEARCH PROBLEM

Introduction and Statement of the Problem

Middle school students are unique and often cited as being the greatest potential "at risk" school population in the country. Students in sixth, seventh, and eighth grade encompass the widest range of intellectual, physical, psychological, and social development within the schools. No other school population has been the focus of such academic, social, and emotional concern. For various reasons, many middle school students are not emotionally, socially, or academically connected with the purposes of school. Youth at risk have the greatest potential of becoming school dropouts.[1] The National Center for Educational Statistics reports that 700,000 adolescents leave school each year by the end of middle school or prior to high school graduation and become dropouts.[2] This student population is termed "disconnected youth" by the Education Commission of the United States.[3] Unfortunately, these disconnected youth move beyond the

[1] Bill Honig, Caught in the Middle Educational Reform for Young Adolescents in California Public Schools, California State Department of Education (Sacramento, California, 1987): 65.

[2] Ibid., 65.

[3] Ibid., 66.

influence of the school community, which provides many young adolescents with some measure of stability and security.

Salvaging these students' lives for moral, ethical, and intellectual reasons, and ultimately the nations' economic and social well-being, is an urgent need which must be addressed. Maeroff questions how long a democratic society can exist when the nation produces thousands of people unable to function in that society.[4]

For many students, the middle grades become the last opportunity to develop a sense of personal academic purpose and commitment to educational goals. Students who fail at the middle grade level often leave school and never again have the chance to develop to their fullest potential. Young adolescents' developmental characteristics must be reconciled with the personal and academic middle school goals.[5]

Purpose of the Study

The purpose of the study was to investigate the middle school students' cognitive developmental level by measuring their performance on Piagetian tasks requiring formal reasoning. The research findings will contribute empirical data to guide educators in lesson development and instructional practices that influence the transition from concrete to formal operations.

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[4] Education USA 27 (1985): 347.

[5] Bill Honig, Caught in the Middle Educational Reform for Young Adolescents in California Public Schools, California State Department of Education (Sacramento, California, 1987): 65.

The importance of this study's research is to provide an understanding of the relationship between age and performance on tasks requiring formal operational thinking. This knowledge should assist educators in planning appropriate tasks to foster formal operational thought development.

General curriculum, lessons and instructional strategies requiring formal reasoning powers beyond middle school students' capabilities prevail in many classrooms. When curriculum is not aligned with the students' cognitive development ability, not appropriately modified or evaluated, the students may lose interest, question their ability, and fail.[6] Curriculum developers and textbook publishers will benefit from research to assist in preparing appropriate materials and tasks for students in cognitive transition. When preparing middle school students to reach their fullest cognitive potential, developing appropriate curriculum requires balancing the concrete and formal operational elements. The relationship between middle school students' age and their performance on tasks requiring formal thought will enhance administrators' knowledge when evaluating teachers, programs, assessment methods, and students who fail in the middle grades.

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[6] Joseph S. Krajcik and Richard E. Haney, "Proportional Reasoning and Achievement in High School Chemistry," School Science and Mathematics, 87 (1987): 25-35.

Background and Need for the Study

Sometime during the secondary school years, formal thought patterns may emerge from concrete foundations. Individuals demonstrating this thinking level use metacognition, the process of reflecting on one's own thinking. At this stage, students have the capability to reason abstractly and solve problems through systematic considerations of possibilities. Formal thought has been described as the summit of cognitive development.[7] Middle school adolescents have the potential to be functioning at the formal operational level, yet many students are still concrete thinkers or in transition. As adolescents transition from the concrete-manipulatory cognitive stage to the capacity for abstract thinking needed for formal operational tasks, the individual's intellectual development range is wide.

Educators in upper elementary, middle, junior, and senior high schools may encounter students demonstrating both concrete and formal reasoning patterns. These are students in a transition phase. Many adolescents avoid thinking critically. Other students may approach formal tasks and problem solving requiring formal thought with great tenacity. Maturity, previous school success, and environment are all factors that influence the transition from concrete to formal operations.[8]

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[7] Roger W. Bybee and Robert B. Sund, Piaget for Educators (Columbus, Ohio: Charles E. Merrill Publishing Company, 1982).

[8] Joseph Krajcik and Richard E. Haney, "Proportional Reasoning and Achievement in High School Chemistry," School Science and Mathematics 87 (1987): 25-35.

For these reasons, Piagetian theory has been criticized for the uncertainty surrounding conclusions based on cognitive developmental stages. Some researchers consider the cognitive stage theory unrealistic, arbitrary, and open to question.[9] Investigators need to assess their methods carefully. Statements inferring that individuals are at a certain cognitive stage, or performing on given tasks as a stage might indicate, must be viewed with extreme caution. Formal reasoning is characterized by several strategies acquired very unevenly. Piaget labels these uneven acquisitions "décalagé," but he does not explain why they occur.[10]

Piaget acknowledged these findings by maintaining that, while not all adults fully develop formal operational thinking processes, they all have the potential to do so.[11] Students can be taught to use higher order thinking skills such as combinatorial thinking, proportionality and hypothetical-deductive reasoning.[12] One of the school's primary task is to focus on the cognitive domain. Knowing the student's potential development in relation to that particular student's actual development can help make instruction more effective. When curriculum is

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[9] Marcia C. Linn, "Theoretical and Practical Significance of Formal Reasoning," Journal of Research in Science Teaching 19, no.9 (December 1982): 727-42.

[10] Ibid.

[11] Mary Carol Day, "Thinking at Piaget's Stage of Formal Operations," Educational Leadership (October 1981): 44-47.

[12] Sandra Falconer Pace, "Students' Thinking: Developmental Framework Cognitive Domain," (Report No. SBN-0-920794-60-2, Alberta Department of Education, Alberta, Canada, 1987), EDRS Document Reproduction Service ED 287570.

mismatched with students' cognitive level, poor academic achievement can result. Middle school students experiencing physical changes and cognitive transition from concrete to formal thinking can be particularly sensitive to inappropriate curriculum. Appropriate tasks will help students develop their full potential. Quality time on suitable tasks along with support will help foster formal thinking.

Educators have the opportunity to help bridge the gap between concrete operational thinking and full formal thinking in the content areas. Understanding the difference between concrete and formal reasoning patterns is important to administrators who can support educators in developing curriculum and evaluating students' progress. This understanding provides direction for teachers attempting to achieve higher thinking levels from their students. Educators must, therefore, assess their methods carefully and develop effective strategies which provide the missing links needed for students to develop into full formal thinkers.

Theoretical Framework

The theoretical framework for this study was based on Jean Piaget's cognitive development theory and significant brain development theory. Research findings describe the interaction between cognitive development theories and brain growth development and their impact on thinking, learning and performance.

Piaget theorized formal operational thought to be the final cognitive development stage, emerging during the adolescent period.[13] Contemporary and

[13] Barbel Inhelder and Jean Piaget, The Growth of Logical Thinking: From Childhood to Adolescence (New York: Basic Books, 1958).

early research based on various cognitive development theories and brain development theories have investigated the validity of Piagetian stage theory. Cognitive development stages and brain development research provide a framework for analyzing adolescent student learning within the middle school setting.

Background

The Swiss epistomologist Jean Piaget ingeniously designed experiments based on observing children. He charted the stages that infants, children and adolescents go through as the mind matures and learning is accomplished. He based his investigation in the 1920s on the notion that children consistently made the same mistakes on certain questions on the newly designed I.Q. test. The errors were systematic and suggested certain universalities in children's thinking at certain stages of development. From his investigations and observations, Piaget formulated hypothesized age-related stages of cognitive development. Characteristics in children's thinking cannot be hurried; cognitive development is a function of experience and maturation and will not emerge until the child's mind is ready. Crucial attributes of the mind, such as space, time, causality, number, and hierarchical structures which are essential to function in the world, appear only in their own time.

Piaget concluded that the mind evolves by active construction. Humans do not passively perceive and process information from the environment. The mind is transformed through interaction, and the transformation evolves in developmental stages according to certain pre-established guidelines.[14]

Jean Piaget's concepts postulated four cognitive development stages corresponding to infancy, early childhood, childhood, and adolescence. These stages are the sensori-motor stage, the pre-operational stage, the concrete operational stage, and the formal operational stage. His notion of developmental milestones made three pivotal suggestions about mind development: first, the mind changes over time; second, the mind changes in ways that depend on the environment; and third, the mind changes in regard to the specific content and mode of thinking.[15]

> Thinking becomes formal as soon as it undertakes the coordination of concrete groupings into a single system because it deals with possible combinations and no longer with objects directly. However hesitating, however incomplete the first trials of formal thinking at the beginnings, we can nevertheless see a tendency toward a new form of equilibrium which is characterized by a new type of structural integration deriving from both the lattice and the group inversions and reciprocities.[16]

The thinking of a bright two-year-old and the sixteen-year-old differs not only in the obvious matters of content but in form. Sixteen-year-olds are able to foresee the consequences of their actions, express themselves in complex sentences, mentally rotate a geometric figure, and defend their opinions using

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[14] Richard M. Restak, M.D., The Mind (New York, New York: Bantam Books, 1988).

[15] Ibid.

[16] Barbel Inhelder and Jean Piaget, The Growth of Logical Thinking: From Childhood to Adolescence (New York: Basic Books, 1958), 293.

quasi-logical arguments. These formal and structural differences between the two age levels are not present at birth but develop according to gene, environment and brain interaction. Mind is present at birth in an elemental form. It does not appear suddenly but emerges from the fertilized egg to the migration of neurons, from birth to interacting with the environment. As the brain matures biologically, it constructs increasingly elaborate rules and structures with which to organize experience and adapt constructively to reality.[17]

Little is known about why responses differ between infants, five-year-olds, adolescents, and adults. It is not known whether event-related potential changes reflect maturational change in the brain's structure or a functional change in the modes of thought postulated by Piaget. Neuroscientists expected that Piaget's stage theory might provide a useful theoretical model for understanding how event-related potentials develop from infancy through adolescence. This correlation of developmental stages occurring but varying at about ages two, seven and eleven was considered a very useful theory for investigating notions on cognitive development.[18]

Although it was generally assumed from Piaget's work that children move developmentally into formal operations at about twelve years of age, later researchers found that, in reality, many adults never reach the formal operational

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[17] Richard M. Restak, M.D., The Infant Mind (Garden City, New York: Double Day & Company, 1986).

[18] Ibid.

stage of cognition.[19] Had Piaget's correlation been sound, it would be possible to define a particular child's developmental standing in relation to that child's evoked potential patterns; this correlation has not been justified in more recent research. A child's performance on a particular task at one developmental stage fails to provide the basis for predicting how the child will later perform at the next stage.[20] Research shows the developmental stages do not occur with the abruptness postulated by Piaget, nor do changes in event-related potentials necessarily signal a shift in the manner a child perceives the world. The important differences between how the infant brain, child brain, and adolescent brain process information add to the uncertainty of developmental stages. The infant brain has the task of gaining information about the world and forming perceptions; the child brain learns how to process information and form concepts; the adolescent brain is transitioning from concrete objects and events for which the adult brain has mentally internalized representations. Cognition is the state of knowing; the acquisition, organization and use of knowledge.[21]

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[19] Barbara C. Decker and Fredrick L. Silverman, "Bridging the Gap From Concrete to Full Operational Thinking in the Content Areas," Presented at the annual meeting of the World Congress on Reading of the International Reading Association (London, England, 1985), EDRS Document Reproduction Service ED 275993.

[20] Richard M. Restak, M.D., The Infant Mind (Garden City, New York: Double Day & Company, 1986).

[21] Ibid.

Research Questions

Answers to the following questions were sought to determine the relationship between cognitive abilities and school performances in middle school students. This information guided the researcher in making recommendations for educational considerations.

1. Are there significant differences in cognitive development at the sixth, seventh, and eighth grade levels for combinatorial thinking, proportionality, or hypothetical-deductive reasoning?

2. Are there significant gender differences (male and female) in cognitive development level for combinatorial thinking, proportionality, or hypothetical-deductive reasoning among middle school students?

3. Are there significant socio-economic status differences (low, medium, and high) in cognitive development level for combinatorial, proportionality, or hypothetical-deductive reasoning among middle school students?

4. What formal thinking ability emerges first--combinatorial (algae), proportionality (frog), or hypothetical-deductive reasoning (mealworm)--among middle school students?

Contribution

The intent of this study was to identify middle school students' cognitive developmental levels and create awareness among middle school educators, textbook publishers, and curriculum developers of the importance of designing appropriate curriculum and choosing appropriate teaching strategies. The contribution of this study promotes action for further research and procedures in middle school education. Through building awareness of cognitive development stages, hopefully educators may be encouraged to design tasks that evaluate the students' cognitive abilities. Teachers should become aware of the need to modify curriculum and teaching strategies to meet the adolescents' cognitive abilities. Educators may learn techniques to develop appropriate tasks that foster students' transition to formal operational thinking. Administrators may gain a heightened awareness for the need to inservice their staff on appropriate instructional and assessment strategies for middle school students.

Definitions of Terms

The following terms are defined for clarity, delimitation, and the specification of the study procedures.

Acetylcholine. A neurotransmitter in the brain, believed to help regulat memory and control the actions of skeletal and smooth muscle in the peripheral nervous system.

Axon. The fiber-like extensions of the neurons by which information is sent to target cells.

Cerebellum. A large structure located at the roof of the hindbrain that helps control movement. It also may be involved in aspects of motor learning.

Cerebral cortex. The outermost layer of the cerebral hemispheres of the brain. It is responsible for all forms of conscious experience, including perception, emotion, thought, and planning.

Cerebral hemispheres. The two specialized halves of the brain formed by a plane through the center, front to back.

Cholinergic pathways. Nerve fiber tracks.

Cognitive development. The formation of learning structures that align with physical development stages.

Combinatorial reasoning. In the study, combinatorial thinking is a formal-level reasoning process indicating the power to classify and categorize objects in exhaustive sets.

Concrete operations. The stage of learning from about age 8 years to 10 years. Students are tied to manipulating concrete objects rather than abstractions.

Darwinism. Charles Darwin's theory of evolution through natural selection and survival of the fittest.

DNA. Deoxyribonucleic acid. The type of nucleic acid considered to be the autoreproducing component of chromosomes and the repository of hereditary characteristics.

Décalagé. French for time lag or jet lag. A term used by Piaget to label the uneven or unpredictable ways children acquire the thinking characteristics of the different stages of cognitive development.

Deductive reasoning. The process of reasoning from the general to the specific to reach a conclusion. Discussed in this study as a formal operational thinking characteristic.

Dendrite. A tree-like extension of the neuron cell body; it receives information from the neurons.

Evoked potentials. A measure of the brain's electrical activity in response to sensory stimuli.

Forebrain. The largest division of the brain, which includes the cerebral cortex and basal ganglia, is credited with the highest intellectual functions.

Formal operational thought. The final mental development stage in which a person is able to hypothesize, use symbols, and deal with abstractions. The cognitive development period from age 11 on. The formal operational stage is used in this study to characterize thinking processes that are no longer tied to concrete objects and reality.

Frontal lobe. One of the four major subdivisions of the two hemispheres of the cerebral cortex.

Glia. Specialized cells that nourish and support neurons.

Hypothetical. Reasoning a formal hypothesis or condition. Used as a hypothetical proposition or judgment. In contrast to categorical and disjunctive propositions.

Inductive reasoning. Reasoning that proceeds from known data to a generalization, such as a theory that will explain the evidence at hand. Inductive reasoning is explained in contrast to deductive reasoning styles in this study.

Lattice. In this study, it refers to cognitive structures used in logico-mathematical thinking as in algebra which uses a particular kind of mathematical system.

Metacognition. The ability to reflect upon, or think about, one's own thinking. Metacognitive statements are used to measure formal operational thinking in evaluating data.

Myelin. Compact fatty material that surrounds and insulates axons of some neurons.

Neuron. Nerve cell, specialized for the transmission of information.

Neurotransmitter. A chemical released by neurons at a synapse for the purpose of relaying information via receptors.

Operations. Actions or processes carried out mentally, rather than physically. Concrete and formal operations in this study refer to mental thought processes.

Piagetian tasks. Paper-and-pencil or hands-on problem-solving puzzles or tests based on Jean Piaget's four stages of cognitive development. In this study, the Piagetian tasks are puzzles that require formal operational thinking.

Proportional thinking. A comparative relationship between things or magnitudes as to size; a ratio. Proportion and proportional logic are operations used in this study to assess the subjects' ability to use formal thinking to set up a ratio as in a math sentence.

<u>RNA</u>. Ribonucleic acide. The type of nucleic acid considered to assist in the functions of protein synthesis.

<u>Synapse</u>. A gap between two neurons that functions as the site of information transfer from one neuron to another.

<u>Temporal lobe</u>. One of the four major subdivisions of the two hemispheres of the cerebral cortex.

<u>Ventricles</u>. Three comparatively large spaces located in the brain: one in the brainstem and the two largest placed above the brainstem on each hemisphere.

Limitations of the Study

The limits deliberately set upon the scope, content and intent of the study by the researcher will be briefly explained. Geographically, the study was confined to a unified school district in East Contra Costa County, California. The population was limited to public middle school students. No attempt was made to identify or eliminate the limited English-speaking population from the sample. The researcher was placed under the constraints of students available on the day the tasks were administered. The sample was slightly diminished in each testing class due to student absence. The diminished sample size did not statistically impact the study, because the absent ratio was proportional throughout the classes. The instrumentation emulated science materials and was restricted to three paper-and-pencil tasks. The tasks assessed formal cognition as related to combinatorial thinking, hypothetical-deductive reasoning and proportionality only.

Finally the time frame was limited to a 45-minute testing period determined by each individual classroom teacher.

The limitations of this study are the internal and external validity and reliability of the instruments. The instruments were designed on the basis of problem solving using formal operational thinking. The instruments transfer Piagetian manipulatory tasks to paper-and-pencil tasks. To answer the three puzzles correctly, combinatorial strategies must be used to solve the Algae Puzzle, proportionality must be used to solve the Frog Puzzle, and hypothetical-deductive reasoning must be used correctly to answer the Mealworm Puzzle.

CHAPTER II

LITERATURE REVIEW

Overview

The findings presented in the literature review were organized and presented under the following three categories: (a) brain development and research; (b) psychological learning theory and research; and (c) characteristic and cognitive ability of adolescent middle school students when performing formal operational tasks.

Brain Development and Research

Introduction

The biological and psychological domains are two well-established research fronts. The biological basis underlying the appearance of thinking capabilities is established by (1) periodic increases in the brain's size and weight[22]; (2) cellular growth within the brain[23]; (3) electrical functioning within the brain.[24] The

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[22] Herman Epstein, "Phrenoblysis: Special Brain and Growth Periods I - Human Brain and Skull Development," Developmental Psycho-biology, 7 (1974): 207-216.

[23] Sandra Ackerman, "Discovering the Brain," To the Institute of Medicine National Academy of Sciences (Washington, D.C.: National Academy Press, 1992).

[24] Joseph Carey (ed. and Public Information Director, Society for Neuroscience), Brain Facts A Primer on the Brain and Nervous System (Woodland, MD: Graphtec Inc., 1993).

sequence in which developmental levels appear contributes to the cognitive capabilities and learning.

The psychological basis is established through (1) the individual's capacity to deal with independent ideas and relate them in increasingly abstract and creative combinations[25]; (2) the individual's ability to relate in social contact and interaction[26]; (3) the individual's ability to exhibit the same kinds of behaviors and views of the world as other individuals and upon growing older to replace each view with a more sophisticated view.[27]

Brain Development

In July 1990 the Institute of Medicine initiated the Decade of the Brain by Presidential Proclamation (see Appendix A). During this decade, basic scientific research is focusing on the nervous system's fundamental workings and clinicians are studying methods for caring for brain and nervous system disorders.[28] With the increased research on the brain, new information is available on brain function, thinking and implications for education.

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[25] Robert Case, "Structures and Strictures, Some Functional Limitations on the Course of Cognitive Growth," Cognitive Psychology, 16 (1974): 544-573.

[26] Lev Semenovick Vygotsky, "The Problem of Age-Periodization of Child Development," Human Development 17 (1974): 24-40.

[27] Jean Piaget, Psychology of Intelligence (Totowa, New Jersey: Littlefield, Adams, and Company, 1969).

[28] Joseph Carey (ed. and Public Information Director, Society for Neuroscience), Brain Facts A Primer on the Brain and Nervous System (Woodland, MD: Graphtec Inc., 1993).

The brain, the physical organ that functions as the integration center for the nervous system, is largely associated with mammals. Among mammals, humans have the largest brain except for whales, porpoises and some other heavy mammals. The adult human brain weighs a little over three pounds and, in volume, a little over a quart. The size and complexity of an animal's brain tends to be directly related to that species' survival needs. The more behaviors an animal needs to find food and avoid danger, the more sensitive the animal must be to its surroundings, the more brain it requires. Because humans must be extremely adaptable and depend on a great number of behaviors to survive, humans demand an exceptionally large brain. The human brain is millions, even billions of times more complex than brains of other animals with true brains.[29]

The human brain regulates life: when one is born, what one can do at the moment of birth, and the chances of survival. The greatest period of brain growth and development occurs after birth with a fourfold increase. Brain growth continues to increase at a frantic rate in the range of two hundred and fifty thousand multiplications per second for one year after birth to accommodate the newborn's needs for survival.[30]

The brain develops from the ectoderm (outer layer of cells). The first thin layer is called the neural plate (125,000 cells present at the beginning). An

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[29] Leslie A. Hart, Human Brain and Human Learning, (New York, New York: Longman, 1983).

[30] Richard M. Restak, M.D., The Infant Mind (Garden City, NY: Double Day & Company, Inc., 1986).

estimated one hundred billion neurons, the key brain cell, form the foundation of all brain functions. The neural plate next folds in on itself to form the neural groove. The groove then closes in on itself to form the neural tube which eventually becomes the spinal cord. From the central canal, the brain's ventricular system develops and three swellings form at the other end of the tube. These three swellings are the beginning structures of the three major brain regions: the forebrain (the cerebral cortex and basal ganglia); the midbrain; and the hind brain (medulla, pons and cerebellum). By the eighth week, the main divisions of the fetal brain are established. In structure, the fetal brain closely resembles the adult brain. Identical cells are transformed into the different parts of the brain through a process called differentiation. The process of differentiation involves three stages: in the first stage, the nerve cells proliferate and specialize; next, the neurons migrate to their final place in the brain; and finally, they mature and establish specific interconnections with other neurons. In this process, the cell layers thicken and the brain becomes larger. The brain's final size and shape depends on this rapid cell multiplication during the nine months before birth. The numbers are staggering. The brain size, however, will undergo early modifications.[31]

Virtually all of the neurons in the human brain are present at birth. Between birth and the end of the first year, the brain will double in size; between age one and age six, the brain will double again in size. The brain cells will get

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[31] Richard M. Restak, M.D., The Mind (New York: Bantam Books, 1988).

bigger, take on insulating sheaths for the cells outside the cortex. A forest of glial cells will nourish the brain's neurons and establish a supporting communication network.[32]

Fetal Brain

From the moment of conception, the brain and behavior are inextricably linked: increasingly sophisticated behaviors require an increasingly sophisticated brain. The fetal brain is perfectly adapted to life in the uterus. The seven-week responses of the fetus kicking its legs against the uterine wall to activate a retropulsive motor movement can spur brain development for balance, coordination and dealing with gravitational forces. "The basic circuits are laid down quite early, then expanded and are modified chemically and functionally by ingrowth of new systems." First, local circuits are established extending from the lower brain stem to influence the behavior of neurons higher up in the cerebral cortex. As additional neurons are added later, already established circuits are altered. This phenomenum of adding the new to the original neurons results in a profound modification of the fetal brain. The brain now becomes organized along fundamentally different patterns. Areas of the brain important in early fetal life gradually lose their power to mold the future of the aging brain.[33]

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[32] Ibid.

[33] Richard M. Restak, M.D., The Infant Mind (Garden City, NY: Double Day & Company Inc., 1986).

Infant Brain

The infant brain is not a tiny version of the adult brain; neurochemically it is different as is its circuitry. The baby's brain comes outfitted at birth with all the neurons it will produce, yet the immature brain still is in the process of growing, establishing millions of synapses, synthesizing neurotransmitters, and increasing in complexity. The baby brain goes through a series of stages, breathes, regulates blood pressure and body temperature, suckles and expresses a repertoire of other motor behaviors based on "circuits" resident in the brain stem. The earliest responses of the newborn baby are simple and repeatable. Much of a newborn's behavior is reflexive and generated from sensori-motor stimulation and patterned in schema. With proper stimulation the baby yawns, hiccups, blinks, and sneezes. Anything put into the baby's mouth elicits salivation. Yawning, stretching, rolling over, smiling when smiled at, fretfulness, laughing are the few true reflex responses.[34]

At about three months, these "lower" brain centers will be taken over by the cerebral cortex and the curious baby reflexive behaviors will cease. At this point in brain development, the baby is no longer an automaton. Memory is not necessary for these reflexive behaviors in the early days in the bassinet. Memory comes later as the infant brain transitions into an adult brain and the cholinergic neurons and fibers form extensions from the forebrain to every other part of the brain.

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[34] Ibid.

The normal infant brain operates on two separate but interrelated channels. The brain generates motor patterns such as sucking, breathing, and stepping while, at the same time, it responds to people and the environment. Brain control involves the successive development and organization and reorganization of compound centers within the brain which may change in place and number according to the needs of the brain as a whole. Motor control is the most important accomplishment of early life, and the greater percentage of brain activity is organized to accomplish these needs. The infant brain is perfectly adapted to achieve the motor milestones of reaching, turning, lifting, sitting up, and ultimately, walking. Taking on algebra will come later. "The healthy infant brain is an age-specific and age-adequate organ."[35]

Brain weight increases between ages 1 and 4. The major components for increased brain weight and size appear to be myelinization, RNA, and protein synthesis.[36] Phrenoblysic growth can account for increase in brain and skull dimensions after age 2 or 3. RNA functions in protein synthesis which would be another contributing factor to increased brain weight.[37]

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[35] Bert C. L. Touwen, as quoted in Richard M. Restak, M.D., The Infant Mind (Garden City, NY: Double Day & Company Inc., 1986), 120.

[36] Herman Epstein, "Phrenoblysis: Special Brain and Growth Periods I - Human Brain and Skull Development," Developmental Psycho-biology, 7 (1974): 207-216.

[37] Myron Winick, "Changes in Nucleic Acid and Protein Content of the Human Brain During Growth," Pediatric Resident 2 (1968): 352-355.

Adolescent Brain

The adolescent brain is best understood by tracing the ontogenesis from the fetal brain. As the environment changes, the brain changes; the transition is not incremental. The adolescent brain must respond to an increasingly sophisticated environment. The infant brain did not need to learn algebra, but the adolescent brain may be called to this challenge. The developing brain must be studied by defining where different neurotransmitters exert their effects, and how they direct one brain region to act in harmony with another region. There is evidence that the activity of a neurotransmitter may alter over time: it may bring about the "firing" of a network of neurons within the infant brain and, at a later time, inhibit nerve cells in that brain as the infant matures into adolescence and adulthood. The last dramatic change in the brain's shape takes place in the prefrontal lobe, directly behind the forehead. This is the part of the brain that directs the rest of the brain, said to be a "top executive officer." It is the part of the brain that handles more intricate and long-term plans. The brain's prefrontal section does not fully mature until at least the late teens or until adulthood.[38] Prefrontal brain development has captured current research. Extensive studies have been conducted comparing cognitive growth cycles with electroencephalogram growth cycles which indicate neurological change. Peaks in cognitive growth align with peaks in electroencephalogram growth, which overlap

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[38] Leslie A. Hart, Human Brain and Human Learning (New York, New York: Longman Inc. 1983).

with Piagetian cognitive development stages. An exception is a decline in electroencephalogram growth in adolescence.[39] The adolescent brain is characterized by a period of refinement attained through the neurological changes in the frontal lobes. While this refinement takes place, the decline in electroencephalic growth may indicate the adolescent brain may not be fully ready for formal abstract thinking.

Early Brain Research

Brain growth and its relationship to cognitive development has been a subject of interest for neuropsychologists and educators. Reliable methods for measuring brain size and growth remain an on-going issue for research.

Broca pioneered the field of craniology and felt the most reliable method to measure brain growth was post-mortem. For obvious reasons, this method proved an impractical method to diagnose a child's readiness for complex skills. Montessori measured head circumference to identify various intellectual abilities of students.[40]

Epstein later studied brain and skull development and termed it Phrenoblysis for spurts in brain and mind. This term was derived from the Greek words "phreno" meaning skull, and "blysis" meaning a welling-up of matter. Epstein based the existence of phrenoblysis in developing humans on the

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[39] R. W. Thatcher, R. A. Walker, S. Guidice, "Human Cerebral Hemispheres Develop at Different Rates and Ages," Science 236 (May 1987): 1110-13.

[40] Anthony D. Pellegrini, "Some Questions about the Basic Tenets of Brain Periodization Research," Journal of Instructional Psychology 11, no. 3 (1984): 165-169.

assumption that increased brain mass would precipitate increased skull size; he correlated data from various brain growth spurt studies and their validity. Other researchers analyzed studies to confirm individuals' peaks and valleys in brain growth.[41] Epstein found in every study significant growth in brain mass during the ages of 2 to 4, 6 to 8, 10 to 12, 15 to 17, and a valley around ages 13 to 14. These studies correlated with the same brain and skull growth. Epstein speculated that the phrenoblysic age spectrum for humans would correlate with spurts in mental ability. Brain growth spurts predicted increases in I.Q. during the same periods. The valley in brain growth during the period from 13 to 14 years could postpone an increase in I.Q. and learning to ages 14 to 16. If Piagetian theory, indicating formal operations to initiate after age 12, is aligned with the valley in phrenoblysic growth, it may be assumed that formal operations may be delayed to ages 14 or older. The 11-year spurt is correlated with the rapid growth and conceptualization about concrete objects. This concrete developmental stage is a precursor for understanding the more abstract ideas of fractions and geometry.[42] This information indicates that formal-level curriculum should be used with caution during the plateau or valley in growth at ages 13 to 14.

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[41] Connie Toepfer, "Brain Growth Periodization: Implications for Middle Grade Education," Schools in the Middle (April 1981): 1-6.

[42] Herman Epstein and Connie Toepfer, "A Neuroscience Basis for Reorganizing Middle Grades Education," Educational Leadership 36 (1978): 656-660.

Contemporary Brain Research

More recent research has relied on electroencephalograms to measure brain growth and developmental spurts. Specific cerebral hemisphere connections were assessed using electroencephalographic measures. Changes in continuous growth functions and discrete growth spurts appearing in specific brain locations at specific ages were indicated by one minute of eye-closed electroencephalograms. Results of these measures showed the left and right cortical brain hemispheres develop at different rates and at different age onsets; five dominant growth periods were evident: from birth to age 3, from ages 4 to 6, from ages 8 to 10, and the fourth and fifth growth periods occurring during adolescence (ages 11 to 14 and ages 15 to adulthood). Other findings reveal the left brain hemisphere leads the right hemisphere in development, but the different hemisphere regions develop at different rates and times; the left frontal lobes achieve 90 percent of adult value by 5 years, the right frontal lobes at 9 years. The brain's growth spurt overlaps with the major developmental stages postulated by Piaget.[43] These growth spurts in the brain support the earlier documentation of Epstein and Toepfer who used different methods to measure brain growth for recommending reorganization of middle grade education.[44]

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[43] Robert W. Thatcher, R. A. Walker, S. Guidice, "Human Cerebral Hemispheres Develop at Different Rates and Ages," Science 236 (May 1987): 1110-13.

[44] Herman Epstein and Connie Toepfer, "A Neuroscience Basis for Reorganizing Middle Grades Education," Educational Leadership 36 (1978): 656-660.

In 1991 further investigations of the brain function organizations were conducted again using the electroencephalogram and measured by alpha-rhythms. The investigations showed that the main developmental trend for brain maturation is manifested as increasing the cortical regions specialization and integration. This integrative activity is the basis for cognitive processes. The molding interaction between the brain centers is a process prolonged and observable throughout the development period.

Integrative brain activity is determined by the maturation, organization and improvement of the neuronal assemblies. Formation and expansion of the horizontal cortical connections creates a basis for the interaction between brain centers. Confirmed again in this research is the impact of maturation on the frontal lobe development.

Frontal Lobe Development

At age 10 frontal cortical integration and specialization result in the individual's increased ability to make general perceptive decisions and behavior reactions to incoming information. This increased integration continues into adolescence with the final development of the frontal region and the final information processing stages. Perception of complex visual stimuli apparent at age 16 to 17 were not evident at early stages of brain development. The maturing frontal region reveals age-related transformation of memory, attention and visual perception to be incomplete from ages 11 to 15. The most dramatic difference between the 10-year-olds and the 16- to 17-year-olds is the subjects' response to imperative stimuli: 10-year-olds can adequately assess the stimuli, as can the 16- to 17-year-olds, but the younger subjects cannot suppress the processing of irrelevant information. This skill is gradual, increasing in 11- to 15-year-olds but not reaching its peak until late teens and into adulthood.[45]

The brain's frontal lobes are responsible for controlling two functions that are most essential for high-level cognitive ability: (1) executive control of new and unique responses; and (2) self-awareness of unique intellectual capabilities (metacognition). The frontal cortex continues to develop hierarchical capabilities until at least age 20.[46]

Between 18 months and 11 years, two developmental waves are identified in which dynamic electrical activity in the frontal cortex is increasingly coordinated with electrical activity in other cortical systems.[47] Both Thatcher and Stuss have implicitly supported the classical metaphor: the frontal lobe system is an orchestra leader whose role is to direct the activity of various other systems. This notion requires the frontal system to establish electro-physiological control of these other systems during the development process. This dynamic hierarchical process continues throughout the physical maturation period. These notions have solid

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[45] D. A. Farber and N. V. Dubrovins Kaya, "Organization of Developing Brain Functions (Age-Related Differences and Some General Principles," Human Physiology 17, no.5 (Sept./Oct. 1991): 326-335.

[46] Donald Stuss, "Biological and Psychological Development of Executive Functions," Brain and Cognition 20 (1992): 8-23.

[47] Robert W. Thatcher, R. A. Walker, S. Guidice, "Human Cerebral Hemispheres Develop at Different Rates and Ages," Science 236 (May 1987): 1110-13.

theoretical grounds and are supported by vast data on cognitive functioning of normal and frontally impaired children and adults.[48]

A striking similarity between electroencephalogram growth cycles and cognitive growth cycles has been documented by contemporary investigators.[49] By comparing Stuss's and Thatcher's data with the data on children's cognitive development, the frontal system development appears more integrated.[50]

During middle childhood changes in capacity for attention occur. The frontal lobes generate novel behavior. Once the available information has been scrutinized, certain pieces of information recognized as important and given special attention and others actively ignored, the subjects can adapt their existing behavioral repertoires to new situations encountered. Maturationally, between ages 4 and 10 there is a marked increase in attentional capacity that acts both to energize and to constrain novel behavior. A decrease in attentional capacity, especially in the area of counting span and spacial span, begins about age 8 and continually fades between ages 10 and 11.[51] This decrease in attention does not show evidence of increase during adolescence.

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[48] Robbie Case, "The Role of the Frontal Lobes in Regulation of Cognitive Development," Brain and Cognition 20 (1992): 51-73.

[49] Robert W. Thatcher, R. A. Walker, S. Guidice, "Human Cerebral Hemispheres Develop at Different Rates and Ages," Science 236 (May 1987): 1110-13.

[50] Robbie Case, "The Role of the Frontal Lobes in Regulation of Cognitive Development," Brain and Cognition 20 (1992): 51-73.

[51] Ibid.

Changes in the power and flexibility of the brain's executive function continues to be studied using Piaget's Balance Beam Task.[52] The relationship between children's working memory as measured by their predictions on Piaget's Balance Beam Task is evident; a delay or acceleration in working memory development corresponds to acceleration or delay in children's balance beam performance. Performance increases with age. Adolescents display flexibility in their thinking as they manipulate the balance beam.

Changes in self-awareness and emotional regulation can be attributed to frontal lobe development. Metacognition, an increase in the child's awareness of his own mental activity begins to emerge between the ages of 6 and 8 and continues to become increasingly sophisticated into adolescence. Adolescents are capable of providing rich accounts of their thinking or planning processes and respond quite well with spontaneous verbal comments.

Similar data on emotional awareness and regulation show that four-year-olds have very little understanding of emotions related to self-evaluation such as pride and embarrassment. Between the ages of 6 and 8 children become increasingly sophisticated in the areas of emotional awareness that peak during adolescence. Inner speech is believed to assume control over children's self-regulation at this time.[53]

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[52] Barbel Inhelder and Jean Piaget, The Growth of Logical Thinking: From Childhood to Adolescence (New York: Basic Books, 1958).

[53] Lev Semenovick Vygotsky, Thinking and Speech, ed. and trans. N. Minnick (New York: Plenum, 1987) (translation of Vygotsky, 1982 b).

It seems reasonable to suggest that the behavioral growth cycle and the electroencephalogram growth cycle are dependent on changes mediated by the frontal brain selection.[54] Children aged 6 to 8 show increased spurts in cognitive growth, yet adolescents do not show this increase.

Edelman's Neural Darwinism Brain Theory

Dramatic developments in brain research and imaging technology enable research to gather information in a few hours which formerly took 20 years of inferential laboratory work with non-human primates. Magnetic Resonance Imaging can distinguish between neuronal groups only a millimeter apart. New biologically based brain research theories focus on the developmental relationship between a brain's ancestors and its current environment. New theories argue that nature plays a far more important role than nurture, as was previously believed. Many current beliefs about instruction, learning and memory are being discounted. Concepts such as parenting, teaching, learning, identity, free will, and human potential may require reconceptualization. Brain evolution influenced by environment suggests a return to Darwinism.[55]

Neural Darwinism, a biological brain theory, is the most comprehensive to date. The 1972 Nobel Prize winner, Gerald Edelman, based his brain research theory on his prize-winning discovery of genetic antibodies. He found that

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[54] Robbie Case, "The Role of the Frontal Lobes in Regulation of Cognitive Development," Brain and Cognition 20 (1992): 51-73.

[55] Robert Sylwester, "What the Biology of the Brain Tells Us About Learning," Educational Leadership, December 1993/January 1994.

humans are born with a vast number of specific antibodies that each respond to a specific harmful invader in the environment; the immune system cannot learn how to destroy an invading bacteria or virus but rather one must be born with the natural immunity. This discovery was applied to investigate whether the brain operates on natural selection or instruction and learning.

Neural Darwinism proposes the brain's dynamic electrochemical system is powerfully influenced by emotions, therefore making the brain's parallel processing more like a jungle's ecosystem than a linear computer. The jungle, characterized by tangled organic excess, is not goal-oriented toward economy and efficiency; plants and animals carry out a variety of symbiotic ecological functions. The jungle environment is not achieved through instruction; no one is taught how to behave in the ecosystem. Evolution works by selection, not instruction. The environment selects from built-in options available; it does not modify or instruct the competing organisms.

In theory, the brain operates in a similar way. The vast interconnected neural network is the equivalent of the jungle. The natural selection processes that shaped the jungle over long periods of time also shape the brain and its neural networks within a lifetime.

The brain's tens of millions of small neural networks respond to a specific environmental element as the immune antibody responds to an antigen. Each neural network processes a single sound, a diagonal line; single responses become interconnected and combine to process more complicated related phenomena; a sound becomes a word, a square becomes a cube. The brain takes relatively small numbers of isolated non-thinking components and combines the information to create a complex cognitive environment. Genetic processes evolving over eons of time have created a common human brain that is fully equipped at birth with the basic sensory/motor components a human needs to function successfully in the normal physical world. Humans are equipped with basic survival systems of circulation, respiration, reflexes, etc., but individuals need to be flexible and adaptable so they can respond to specific environmental challenges.[56] Sylwester restates the important role of the infant brain in the process of ontogenesis earlier formulated by Restak.[57] The infant brain cannot be isolated from the adolescent brain which is directly affected by development and encoding from infancy.

The infant brain does not have to learn how to recognize specific sounds and visual stimuli; these basic neural networks are functioning at birth. A child does not need to be taught to walk and talk; opportunities for adaptation are provided for an already operating process.

The DNA encodes a basic developmental program that regulates how neurons will differentiate and interconnect. The fetal brain develops general areas that are assigned to various basic human capabilities within a certain range and variation, such as the ability to process language. Infant brains come equipped to

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[56] Gerald Edelman, Bright Air, Brilliant Fire: On the Matter of the Mind (New York: Basic Books, 1992).

[57] Richard M. Restak, M.D., The Infant Mind (Garden City, NY: Double Day & Company Inc., 1986).

speak any of 3000-plus human languages. The infant brain is not proficient in any language but the process of language development is universal, multicultural. Basic rules of grammar, prepositional phrases and native accents are not deliberately taught.

Language usage selectively strengthens and weakens specific language networks. Sound networks that are not in the local language atrophy from lack of use or are used for other language purposes. This phenomena is expressed in Japanese adults' difficulty or inability to pronounce the "L" or "R" sound in English. A Japanese child who learns English will have no trouble as an adult speaking the "L" or "R" sound. This physiological phenomena is called fossilization. The brain loses its capability around adolescence to lose the accent from the primary language when speaking the second language.[58]

In life, humans discover what is already built into their brains. What is considered learning is an individual's search through the brain's existing store of operating networks for the combinations of those that allow us to respond to the immediate challenge.[59]

Psychological Learning Theory and Research

> For many centuries, philosophers and others who have studied the human mind have believed that reasoning takes place according to the laws governing logic. Or rather, that it should, but regrettably

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[58] Robert Sylwester, "What the Biology of the Brain Tells Us About Learning," Educational Leadership, December 1993/January 1994.

[59] Michael Gazzaniga, Natures Mind: The Biological Roots of Thinking, Emotions, Sexuality, Language and Intelligence (New York: Basic Books, 1992).

> often fails to do so... Such is the tradition that runs unbroken from Aristotle to Piaget. But findings of cognitive science run counter to it: logical reasoning is not our usual or natural practice, and the technically invalid kinds of reasoning we generally employ work rather well in most of everyday situations in which one might suppose rigorous deductive thinking was essential.[60]

Jean Piaget, a Swiss scientific epistomologist, contributed an approach to cognitive psychology based on knowledge development. Piaget used scientific observations and inquiry to investigate knowledge growth. His research began in the 1920s and focused on the child's growing ability to use number sense appropriately, classify objects, and develop reasoning for science and formal abstract analysis. Piaget was interested in the relationship between the child's biological growth and cognitive development. Attempting to study knowledge scientifically, Piaget investigated the relationships between genetics and knowledge development.[61]

Piaget's approach to the study of knowledge was developmental. Piaget considered knowledge development to be genetic, and he applied this concept in order to study knowledge scientifically. Piaget recognized that knowledge was always in the process of development. The study of the growth of the child's understanding was particularly appropriate to examine in relation to the

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[60] Morton Hunt, The Universe Within (New York: Simon & Schuster, 1982), 121.

[61] Roger W. Bybee and Robert B. Sund, Piaget for Educators (Columbus, Ohio: Charles E. Merrill Publishing Company, 1982).

understanding of events. Cognitive developmental psychology for Piaget was the most available and appropriate vehicle for his study of genetic epistemology.[62]

Piaget's Cognitive Development Stage Theory

Jean Piaget postulated four cognitive development stages corresponding to infancy, early childhood, childhood and adolescence. These stages are termed sensory-motor, preoperational, concrete, and formal. The intellectual structures of formal though between birth and the period of 12 to 15 years grow slowly but in relation to the physical developmental structures. The order of physical development stages is extremely regular, but the speed can vary from one individual to another.[63]

The average age at which children go through each stage can vary considerably from one social environment to another, from one type of school to another, from one region to another, or from one country to another. Differences in developmental speed, without modifications in the order of stage sequence, would be contributed to the quality and frequency of intellectual adult stimulation, peer interactions, and environmental influences. If the sensory motor, preoperational and concrete development periods are slowed down due to poor stimulation and activity, formal thought formation will show greater retardation. Formal thought could be delayed to between 15 and 20 years of age rather than

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[62] Ibid.

[63] Jean Piaget, "Intellectual Evolution from Adolescence to Adulthood," Human Development 15 (1972): 1-12.

the theorized age span of between 11 and 15 years.[64] Although it is generally assumed from Piaget's work that children move developmentally into formal operations at about 12 years of age, later researchers found, in reality, many adults never reach formal operational cognition.[65] In extremely disadvantageous conditions, formal thought will never really take shape unless the individuals change their environment while development is still possible.

The first interpretation concerning the acquisition of formal though suggests all normal individuals are capable of reaching the formal developmental level if their social environment provides cognitive nourishment and intellectual stimulation. A second interpretation which excludes certain individuals even in favorable environments from attaining formal operation thinking is diversification of aptitude with age. In this model, general skill attainment is associated with development, but after a certain age, individual aptitudes become more important than the general characteristics and create greater and greater differences between subjects. The third interpretation regarding formal operational thought reconciles developmental stages with progressively differentiating aptitudes. In this model, all normal subjects would attain formal operational structures between ages 11-12 to 14-15 years or by age 20. They will reach formal operational thinking in

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[64] Ibid.

[65] Barbara Decker and Frederico L. Silverman, "Bridging the Gap From Concrete to Full Operational Thinking in the Content Areas, Presented at the annual meeting of the World Congress on Reading of the International Reading Association (London, England, 1985), EDRS Document Reproduction Service ED 275993.

different areas according to their aptitude and their professional specialization. Formal structures will vary and be used differently from one person to another.[66]

Vygotsky's Socially Shared Cognitive Development Theory

Vygotsky associated social origin with mental processes and emphasis on physical development stages. Vygotsky's notion of cognitive and physical development argued that two lines of development, the cultural line and the natural line, come into contact and transform one another to form the child's personality. The most adequate way to understand human mental functioning is to trace it back through developmental changes, from birth to death. Vygotsky says, "It is only in movement that the body shows its essence." The history of behavior forms its very base. Developmental psychology and human mental functioning can be understood by investigating how the various genetic domains operate within an integrated system. Primates attempt to master their behavior with the use and invention of tools. Human speech and other psychological tools signify the beginning of genuine cultural or historical behavior development. In child development, organic growth and maturation share the cultural growth of behavior. Socio-cultural products are appropriated by mediational means as individuals carry out mental functioning.[67] The interaction between the

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[66] Jean Piaget, Psychology of Intelligence (Totowa, New Jersey: Littlefield, Adams and Company, 1969).

[67] Lev Semenovick Vygotsky, Mind in Society: The Development of Higher Psychological Processes, eds. M. Cole, V. John-Steiner, S. Scribner, and E. Souberman (Cambridge, MA: Harvard University Press, 1978).

individual and the cultural tools inherently involves mediated action. The complex psychological tools that alter the entire flow of behavior and mental structures include: language, various systems of counting, mnemonic techniques, algebraic systems, works of art, writing, schemes, diagrams, maps, mechanical drawings, and conventional signs. Each individual uses the tools in unique concrete instances.

A new upsurge in Vygotsky's ideas has emerged in Western culture, especially in the United States. Psychological terms such as socially shared cognition, socially distributed cognition and collective memory have appeared in recent literature and research to describe a more contemporary paradigm for cognition. Vygotsky's ideas seem to address the search for new theoretical frameworks on mental functioning and appear directly relevant to issues in education and other applied fields. Vygotsky's view of psychological phenomena is based on his claims of social origins and "quasi-social nature" of intramental functioning. He views mental functioning as a kind of action that may be carried out by individuals, by dyads, and by larger groups. Vygotsky called it "extending beyond the skin." Mind, cognition, and memory are understood as functions carried out intermentally or intramentally, not as attributes or properties of the individual.[68]

[68] James V. Wertsch and Peter Tulviste, "L.S. Vygotsky and Contemporary Developmental Psychology," Developmental Psychology 28 (1992): 548-557.

Contemporary Developmental Psychology Theories

Two issues that have taken on particular importance in Western contemporary developmental psychology and have a specific impact on student intelligence, learning, and assessment are "zone of proximal development" and "egocentric" and "inner speech." "Zone of proximal development" refers to the child's actual developmental level and potential developmental level. This is measured through independent problem solving and higher level potential by problem solving under adult guidance or in collaboration with more capable peers.[69]

The direct implication of the "zone of proximal development" for the organization of instruction is that instruction should be tied more closely to the potential developmental level not to the actual developmental level. For assessing intelligence, measuring potential developmental level and actual developmental level are equally as important. Through this approach, educators can take children at the same developmental level but unequal in their immediate performance or potential development and help move them to "zone of proximal development." With assistance, the processes of mental development, those completed today and yesterday, those in the maturation processes that are

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[69] Ibid.

completed, those now in the ripening state or only developing can be taken into account.[70]

"Inner speech" enables humans to plan and regulate their actions based on previous participation in verbal social interaction. "Egocentric speech" is found in the transition from external to inner speech. "Egocentric speech" reflects the inability of young children to differentiate and self-regulate their actions within the social context.[71]

Currently two American research programs have sought to confirm and build upon "inner speech" and "egocentric speech." Through studying "private speech" conversations children have with themselves, researchers found once cognitive operations become well practiced, children start to think words rather than say them. Self-guidance is the central function of "private speech." Private speech becomes "inner speech," conscious dialogues individuals hold with themselves while thinking, acting, and problem solving.[72]

Gardner's Multiple Intelligence Theory

Gardner's Theory of Multiple Intelligence identified seven different intelligences possessed by most people: linguistic, logical-mathematical, spatial,

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[70] Lev Semenovick Vygotsky, Mind in Society: The Development of Higher Psychological Processes, eds. M. Cole, V. John-Steiner, S. Scribner, and E. Souberman (Cambridge, MA: Harvard University Press, 1978).

[71] Lev Semenovick Vygotsky, Thinking and Speech, ed. and trans. N. Minnick (New York: Plenum, 1987) (translation of Vygotsky, 1982 b).

[72] Laura E. Berk, "Why Children Talk to Themselves," Scientific American 271 (1994): 78-83.

musical, bodily kinesthetic, interpersonal, and intrapersonal. His theory involves the use of problem-solving skills that enable people to resolve genuine problems, create effective products, and find and create new problems. Gardner concurs with Vygotsky that both the problems and the products must be relevant in a particular cultural context. Although evidence of the seven intelligences may be used by all, most people are not gifted or highly competent in all seven intelligences. Gardner believes development of high-level competence requires innate capacity, motivation, and opportunity which may be influenced by environment, cultural context, and language. Individual giftedness may not be determined by environment, cultural context, and language but may influence the specific ways it is expressed. The predominant modes used by individual cultures may determine the way the gifted intelligence is expressed.[73] Some cultures may foster linguistic giftedness because oral expression is valued; other cultures may value writing novels, and therefore, giftedness could occur more naturally in written expression. The culture's grammatic form of language may influence the expression of both linguistic and logical-mathematical giftedness. Languages in which nouns come first may contribute to holistic thinking styles, while using languages in which adjectives come first may contribute to a more linear, analytic thinking style.[74]

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[73] Howard Gardner, Frames of Mind: The Theory of Multiple Intelligences (New York: Basic Books, 1983).

[74] C. June Maker, "Identification of Gifted Minority Students: A National Problem and an Emerging Paradigm," Manuscript submitted for publication, 1994.

For Vygotsky, the individual carries out mental functioning through mediated action between the cultural tools and the psychological tools: language, counting systems, mnemonic techniques, algebraic systems, art, writing, and conventional signs. Each individual uses the tools in unique concrete instances which can be associated with competence and giftedness. Gardner's seven intelligences align nicely with Vygotsky's complex psychological tools.

Influences on Learning

As early as 1911, Nobel Prize winning anatomist, Ramon y Cajal, realized that no nerve cells could be produced after birth in the cerebral cortex, but he proposed that cells could get bigger with "cerebral exercise." New and more numerous connections between the brain's nerve cells could be established through enhanced environments.

Environment, family values, and other various factors can influence student opportunities and motivation for developing competence and giftedness. Children who grow up in isolated rural areas may have fewer opportunities to develop certain interpersonal skills but have more opportunities to self-reflect and become more introspective than children growing up in cities. Children whose parents are musicians have more opportunities to develop musical ability than children who have not been exposed to music. Children whose parents are kinesthetic and participate in physical activities and hands-on mechanical projects are more likely to have mechanical ability and physical skills than children whose parents never use tools and machinery.[75]

The list of environmental influences is endless, yet one can understand the advantages individuals have who are exposed to or saturated with various cultural opportunities. Gardner's theory seems to tie together Piaget's and Vygotsky's ideas. For Piaget, formal thought can vary from one region or country to another and can be affected by adult and peer interactions and environmental influences. Formal operational thinking, which can be associated with competence or giftedness, may be expressed in different areas according to the individual's aptitude or professional specialization.[76]

A positive correlation between brain chemistry and learning ability[77] was confirmed in the late 1950s when a neuroanatomy group at the University of California at Berkeley found that rats who had spent time in stimulating environments had brains with greater cortical thickening and larger nerve cell dimensions than their brothers living in impoverished conditions. This team was among the first to broaden the knowledge base for neurotransmitters. They

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[75] C. June Maker, Aleene B. Nielson, Judith A. Rogers, "Giftedness, Diversity, and Problem-Solving," The Council for Exceptional Children, Teaching Exceptional Children, 27, no.1 (Fall 1994): 4-18.

[76] Jean Piaget, "Intellectual Evolution from Adolescence to Adulthood," Human Development 15 (1972): 1-12.

[77] Marian C. Diamond, Enriching Heredity The Impact of the Environment on the Anatomy of the Brain (New York: The Free Press, 1988).

measured acetylcholine's hydrolyzing enzyme acetylcholines-terase and found this enzyme in the maze-bright rats more abundant than in maze-dull rats.

Characteristics and Cognitive Ability of Adolescent Middle School Students When Performing Formal Operational Tasks

Introduction

Middle school students have been described as both refreshing and fragile, unique yet bemusing. Middle school students acquire considerable intellectual sophistication as they search for autonomy and identity. They expend boundless energy toward peer approval and exploring new horizons.[78]

Middle school students, who are identified as between the ages 9 and 14 and in grades 6, 7, 8, and 9, may attend middle school grades 6, 7, and 8, intermediate school grades 7 and 8, or junior high grades 7, 8, and 9. One way to understand middle school students is to consider the major skills they should acquire and the tasks they should accomplish. These developmental tasks and skills fall in the physical, intellectual, and social domains. Developmental tasks are defined as the skills, knowledge, functions, or attitudes an individual normally acquires during a specific period or age range.[79]

Adolescent Characteristics

Under physical development, skill attainment includes becoming aware of increased physical changes; under intellectual development, skill attainment

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[78] Hershel D. Thornburg, "The Counselor's Impact on Middle Grade Students," School Counselor 33, no.3 (1986): 170-177.

[79] Ibid.

includes organizing knowledge and concepts into problem-solving strategies and making the transition from concrete to abstract symbols (a new task); under social development, skill attainment includes learning new social and sex roles, identifying with stereotype role models, developing friendships, gaining a sense of independence, and developing a sense of responsibility. These tasks should be either fulfilled or initiated in the course of normal development.[80] The degree to which middle school students can identify and cope with these new tasks influences their ability to effectively function during adolescence.

Middle school students are keenly aware of their bodies' physical changes. Individual differences among the sexes and between the sexes can cause anxiety. The female growth spurt usually begins at age 10. The current mean age for female menarche is 12.8 years; for black girls, one year earlier. Males begin their growth spurt around age 12 and begin tapering off by age 14. The middle school boy's development is behind his female counterpart and is not comparable until the male reaches age 16. It is important for middle school students to understand that variation in growth is normal and to foster personal acceptance and individual differences.

Intellectual changes are not as easy to observe as physical changes in adolescents, but are just as dramatic. Mental changes may cause a difficult

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[80] Ibid.

adjustment period and often occur before the physical changes.[81] It is important to understand that formal operational thinking is not a continuous process. There is great variation in the age at which young adolescents enter the formal operational stage as well as the rate at which they assimilate and accommodate the actions and operations.[82]

In the early formal cognitive stage, during ages 11 and 12, students begin to form superordinate concepts about objects and their relationship among other groups. The learner has the ability to realize if one collection of objects is included in another, then all the objects in the smaller group are part of some larger group; the converse is also true. The ability to overlap a concept map as in a Venn diagram or coordinate graphing requires integrating earlier concepts. Forming and integrating new concept maps continues through adolescence and into adulthood.

Students at this age can look at different objects and begin to abstract their common characteristics which leads to more abstract conceptualization. For example, students should be capable of looking at several differently shaped five-sided figures and determine the common elements among them. After

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[81] C. Kenneth McEwin and Julia T. Thomason, Who They Are-How We Teach: Early Adolescents and Their Teachers (Columbus, Ohio: National Middle School Association, 1989).

[82] John Van Hoose and David Strahan, Young Adolescent Development and School Practices: Promoting Harmony (Columbus, Ohio: National Middle School Association, 1988).

establishing a set of common properties, the student should be able to generalize the word "pentagon" to any figure with five sides.

About age 13 the students become more flexible in their thinking. This marks the beginning of middle formal operations. Students can organize and then reorganize (horizontal reclassifying) a collection of objects or ideas in different ways.[83] They have the ability to reason through permutations and employ combinatorial reasoning. The task's purpose determines how the organization takes place. Students use this new intellectual capacity without the need to manipulate physical objects. Now symbols are understood and used easily. Reality becomes secondary to possibility. Students can identify, separate and test variables and formulate hypotheses.[84]

The process of developing strategies for formal thinking is unique among adolescents. An adolescent may be able to think abstractly in some areas but not in others. Some general characteristics do prevail among the adolescent population. In addition to the wide cognitive range and individualization among students during the transition from the concrete-manipulatory stage to abstract-formal thinking, adolescents are intensely curious, prefer active to passive learning experiences, favor learning activities involving peer interactions, exhibit a strong

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[83] Anton E. Lawson and John Renner, "Piagetian Theory and Biology Teaching," American Biology Teacher 37 (1975): 336-343.

[84] Lawrence F. Lowery, Thinking and Learning Matching Developmental Stages With Curriculum and Instruction (Pacific Grove, California: Midwest Publications, 1989).

willingness to learn concepts and skills they consider useful, enjoy solving real-life problems, are egocentric, argue to convince others, exhibit independent, critical thinking, and experience the phenomenon of metacognition. While displaying these characteristics, adolescents consider academic goals second in priority to the personal-social concerns that dominate their thoughts and activities.[85]

Adolescent Problem-Solving Strategies

The organization of knowledge and concepts into problem-solving strategies occurs as a gradual progression of concepts that should have been mastered in elementary school. Conservation (absoluteness) of weight, volume, and number and the ability to classify, order, and group objects is a precursor to higher levels of thinking. As the external world and internal cognitive knowledge bases on which the student operates increase with age, their knowledge and skill expands. With development, the quality of thinking along with the knowledge base get broader. Middle school students should have less need to deal only in concrete concepts and learn that symbols or strategies can be used in various situations and move beyond a specific context. This ability to generalize is a prerequisite to learning strategies for problem-solving. Concept learning creates a foundation for learning new information and retrieving relevant learned information.

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[85] Jo Sue Whisler, "Young Adolescents and Middle Education: A Review of Current Issues, Concerns, and Recommendations," Mid-Continent Regional Educational Laboratory, sponsored by: Office of Educational Research and Improvement (ED), Washington, DC (Aurora, Colorado, 1990), ERIC Document Reproduction Service ED 346960.

The students' ability to move from concrete to abstract thinking probably begins when middle graders use concrete manipulation for abstract thinking, and as the individual's abstract abilities become better defined, the concrete reference points gradually disappear. As middle graders increase their capacity for abstract thoughts, there is the tendency to abandon the less flexible concrete thought patterns for the more flexible abstract reasoning patterns. The more flexible abstract reasoning is characterized by the ability to see relationships between ideas and going beyond the literal interpretation of the classroom materials' general content and applying the presented information to other situations.

The transition from concrete thinking to abstract thinking occurs in the middle grades. Most educators in upper elementary, middle, and junior high encounter students demonstrating reasoning patterns that have both concrete and formal elements; these students are in transition. Many adolescents avoid thinking critically, perhaps because it might result in negative consequences or demean their intellect or self-concept. Other students may approach formal problem solving and formal tasks with great tenacity. Maturity, previous school success, and environment are all factors that influence concrete to formal operational thinking.[86] Socio-economic status has been suggested as affecting school performance and progression into higher levels of thinking. Children of parents in low socio-economic status areas, presumably having lower levels of schooling,

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[86] Roger W. Bybee and Robert B. Sund, Piaget for Educators (Columbus, Ohio: Charles E. Merrill Publishing Company, 1982).

have less continuity between the home and school environment. The interaction in schooled families more closely resembles interactions occurring in school classrooms.[87]

It is important to understand that adolescents have predominantly concrete thoughts. During the middle grades, only a small group of students will become abstract thinkers, most will not become abstract-dominant.[88] Curriculum must be designed to provide experiences to help students transition into formal abstract thinking.

The beginning of the formal operations stage, described in research as the inclusive classifying stage, is characterized by the students' ability to conceptualize ideas that are remote in time and space. At this stage students can learn the abstractness of bird, a superordinate term representing many varieties of birds. Similar abstract terms such as justice, freedom, gravity, or phyla can be understood by 11- and 12-year-olds if the proper experiences have been made available for the conceptualization to take place.

Students' ability to mentally move between concrete and abstract ideas enables students to learn problem solving based on disconnected factors; they can

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[87] Lorene C. Quay, "Interactions of Stimulus Materials, Age, and SES in the Assessment of Cognitive Abilities," Journal of Applied Developmental Psychology 10, no.3 (July-Sept 1989): 401-409.

[88] Hershel D. Thornburg, "The Counselor's Impact on Middle Grade Students," The School Counselor, 33, no. 3 (1986): 170-177.

reorganize facts or events that will reveal new connections. At this time concrete thinking begins to move into formal thinking.

The middle formal operations stage, described in research as the horizontal classifying stage, is characterized by the students' ability to reclassify the same materials over and over again without any new ones being added or old ones taken away. This process indicates a flexibility in the individuals' organizational ability. Experiences must be provided for these students to identify and isolate relationships and combinations to solve complex problems later in their personal and professional lives.[89]

One major misunderstanding is the theory that middle school students should become more sophisticated and abstract in their thinking. Research shows that concrete thinking commonly prevails among middle school students and often concrete thinkers are labeled as having learning problems. The problems that students encounter are tied to their cognitive development transition. Middle school students having difficulty with abstract thinking frequently find it impossible to cope and turn off to school curriculum demands. Unfortunately, parents and educators misunderstand the capabilities of middle school students. Middle school students are not incapable of understanding complex thinking processes and new subject matter. To help students transition from concrete thinking to abstract

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[89] Lawrence F. Lowery, Thinking and Learning Matching Developmental Stages With Curriculum and Instruction (Pacific Grove, California: Midwest Publications, 1989).

thinking, they must be taught the necessary new language and thought processes.[90] Curriculum intervention has been used to help move concrete thinkers into formal abstract thinkers. Greater student achievements in science, mathematics and metacognition were attained through lesson enhancement.[91]

Adolescents' Performance on Research Tasks

Adolescents performing researcher-designed paper-and-pencil tasks to assess formal operational thinking do not vary from performance on tasks using Inhelder's and Piaget's formal operational tasks.[92] One investigation using Piaget's chemistry experiment, combining solutions, found a low correlation between adolescents' performance on the chemistry task and performance on a diagnostic problem-solving task. Neimark found the chemistry task provided an irresistible stimulus for students to manipulate and play with the chemicals. This incitement brought the students' performance to a lower level of operations which seemed to overshadow any analytic problem solving which a student might not normally bring to the experimental situation. The students, however, could

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[90] Hershel D. Thornburg, K. L. Adey and E. Finnis, "A Comparison of Gifted and Nongifted Early Adolescents' Movement Toward Abstract Thinking," Paper presented at the annual meeting of the American Educational Research Association, Chicago, Illinois, March 1985.

[91] Michael Shayer and Philip S. Adey, "Accelerating the Development of Formal Thinking in Middle and High School Students IV: Three Years After a Two-Year Intervention," Journal of Research in Science Teaching 30, no. 4 (1993): 351-366.

[92] James J. Roberge and Barbara K. Flexer, "Further Examination of Formal Operational Reasoning Abilities," Child Development 50 (June 1979), 478-484.

perform at the formal level on the combinatorial tasks.[93] Proportional reasoning ability seems to be a factor related to success in chemistry as well as a characteristic of formal operational thinking. The American Chemical Society--National Science Teachers Association High School Chemistry Achievement Examinations (ACS) show 18 of the 31 test discriminators require the use of proportional reasoning.[94]

Adolescents appear to acquire formal operational skills first in combinatorial thinking, second in propositional logic or hypothetical-deductive reasoning, and last in proportionality. There is little evidence of functional interdependence among the logical operations, nor is there any support that these skills are acquired with synchronization.[95]

The relationship between cognitive developmental levels and integrated processing skills as measured by middle school students conducting and designing experiments, formulating hypotheses, making generalizations and collecting data has a significant correlation ($r = 0.73$). Developmental levels appear to be universal. Junior high school students in North Carolina and Japan performed tests of logical thinking and processing skills. Although the general overall means

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[93] Edith D. Neimark, "A Preliminary Search for Formal Operations Structures," The Journal of Genetic Psychology 116 (1970): 223-232.

[94] Joseph S. Krajcik and Richard E. Haney, "Proportional Reasoning and Achievement in High School Chemistry, School Science and Mathematics 87, no.1 (Jan. 1987): 25-32.

[95] James J. Roberge and Barbara K. Flexer, "Further Examination of Formal Operational Reasoning Abilities," Child Development, 50 (June 1979), 478-484.

for performance on proportionality, probability, combinatorial thinking, and controlling variables was higher for the Japanese middle school students than North Carolina middle school students, in both groups the direction of change was positive with increasing grade level. In Japan, a higher percentage of students was performing at the formal level of thinking or in transition compared to North Carolina students.[96] As in the investigation by Roberge and Flexer, the overall student performance indicated formal operational thinking develops first in combinatorial thinking, second in controlling variables, and last in proportionality.[97]

Adolescent Curriculum Performance

The students' ability to organize and reorganize and see relationships among ideas is evident across the curricular areas. Analogies, advanced ideas that express relationships between two similar things compared to two other similar things (A/B = C/D), can be comprehended by students in the early stages of formal cognitive development. In all subject areas, analogies are advanced ideas expressing similarities among relations but not a direct similarity between things. The relationship is the expressed idea, not the similarity. In mathematics,

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[96] Floyd E. Mattheis, William E. Spooner, Charles R. Coble, Shigekazu Takemura and Shinji Matsumoto, Katsunobu Matsumoto, Atsushi Yoshida, "A Study of the Logical Thinking Skills and Integrated Process Skills of Junior High Students in North Carolina and Japan," Science Education 76, no. 2 (1992): 211-222.

[97] James J. Roberge and Barbara K. Flexer, "Further Examination of Formal Operational Reasoning Abilities," Child Development, 50 (June 1979), 478-484.

analogies can help middle school students understand that a triangle is to a pyramid as a square is to a cube, that a circle is to a sphere as a wheel is to an orange. In the science technology it can be understood that germ is to disease as war is to destruction; that telephone is to letter as sight is to sound. In the social sciences beginning formal thinkers can understand that immigration is to entrance as emigration is to departure. Adolescents have the ability to learn the symmetrical relationship involved in international trade and reciprocal trade agreements. In science they can conceptualize systems and their interactive relationships of their parts: solar system (sun, moon, and planets) and the digestive system (stomach, intestines, colon). Later in the middle grades (8 and 9) students can reason through "if/then" statements and understand causal relationships in phenomena as in photosynthesis and can learn ratios and proportionality.[98] Studies assessing formal thinking in social situations involving interactions in the interpersonal world found adolescents too egocentric to respond critically to social situations.[99] Formal thinking involving social

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[98] Lawrence F. Lowery, Thinking and Learning Matching Developmental Stages with Curriculum and Instruction (Pacific Grove, CA: Midwest Publications, 1988).

[99] David Elkind, "Egocentrism in Adolescence," Child Development 38 (1969): 1025-1034.

situations has been found to be significantly affected by age, education, and experience.[100]

Reading success has been attributed to cognitive maturity. Formal thinkers use better judgment in knowing when to skim, can construct tentative hypotheses from past experiences, can summarize and conclude the main idea, ignore the face value of words and consider their meaning in terms of the context. Formal thinkers can strive to form concepts beyond the story line.[101] In the early stages of formal operational thought, students can analyze stories for the author's main idea. Formal operational readers use combinatorial thinking when reading. The reader is a problem solver who looks at all the possibilities or combinations to find solutions. The formal readers are reflective and questioning; they display skepticism when reading. Mature readers seek crucial logical links in the arguments the authors weave. The formal reader seeks the author's biases and is less susceptible to psychologically persuasive fallacies.[102]

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[100] William Gary and Mary Lou Rush, "Formal Operations and Social Relativistic Thinking,"Presented at the Sixteenth Annual Symposium of the Jean Piaget Society, Philadelphia, 1986 (Center for Applied Cognitive Science, The University of Toledo, Toledo, Ohio), EDRS Document Reproduction Service 270235.

[101] Barbara Decker and Frederick L. Silverman, "Bridging the Gap From Concrete to Full Operational Thinking in the Content Areas," Presented at the annual meeting of the World Congress on Reading of the International Reading Association (London, England, 1985), EDRS Document Reproduction Service ED 275993.

[102] Stephan Friedman and George Kilodiy, "A Model Program for Development of Verbal and Quantitative Reasoning Skills," Problem Solving 5 (1983): 1-5.

In writing, young adolescents can construct outlines and concept maps for their own writing. They can learn and use analogies and metaphors. Research shows that adolescents have the ability to write paragraphs in terms of inductive and deductive logic. Movement from general to specific terms and chronological and spatial arrangements are well within the capabilities of adolescents. There is a statistically significant relationship between age and the amount of spelling and mechanical errors; young writers make more errors.[103] Adolescents exhibit formal operations by writing a more complete sentence with increasing numbers of subordinate clauses. Performance on Piagetian tasks was correlated with sentence length as determined by the number of words (T-Units). Male performance on the Piagetian proportional task correlated with the length of sentence ($r = 0.58$).[104] When 25 female and 25 male 14-year-olds were administered a 500-word written task and 15 Piagetian formal reasoning tasks involving the conservation of weight, displaced volume, controlling variables, proportional reasoning, probability, and combinatorial reasoning, the proportion task correlated significantly with mean T-Unit length ($r = 0.58, p < .01$). In contrast, the correlation for the combinatorial logic task was not significant ($r = 0.28$). The

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[103] Joseph G. Martinez and Nancy C. Martinez, "Are Basic Writers Cognitively Different?" Paper presented at the WCRLA Conference, 1987, EDRS Document Reproduction Service ED 285179.

[104] Anton E. Lawson and Gene D. Shepherd, "Written Language Maturity and Formal Reasoning in Male and Female Adolescents," Language and Speech 22 (1978): 117-127.

cumulative reasoning score correlated ($r = 0.59, p < .001$) with mean T-Unit length.

Neo-Piagetian Theory

Neo-Piagetian theorists continue to research and challenge classical Piagetian stage theory. The basic premise for investigation is whether adolescents' understanding of social and non-social worlds proceeds in the traditional Piagetian sequence.

Neo-Piagetian theorists have attempted to provide a general basis for assessing the complexity of formal thought in adolescents. Their notion is children can first handle one new abstract element, then two, and then multiple abstract elements simultaneously. Neo-Piagetian theorists have suggested that adolescents can operate at a new and more abstract cognitive level because they can integrate the skills from the concrete operational stage and are less dependent on symbolic logic. The distinction between the complexity or content of adolescents' reasoning makes it possible to classify any form of reasoning, concrete or formal, independent of a particular domain of knowledge aside from domains where formal logic is not involved.

The nature and timing of adolescent thinking was investigated using the Piagetian Balance Beam Task and the Personality Diagnosis Task to determine if thought changes are domain-specific. The data revealed an ordinal developmental sequence with a general rate in the progression through the tasks: 64 percent of the subjects performed at the same level on both tasks, and 33 percent of the subjects functioned at different developmental levels across the two tasks.

This study concluded that the change in adolescents' capabilities is a change in potential. This change is exhibited when: (1) the student is familiar with the situation and has requisite knowledge; (2) the child has not had a lot of previous experience with a particular situation; and, (3) some kind of high-level problem-solving is required and is not aided by perceptual or social cuing.

The data and statistics indicate that cognitive development at the formal level is not a lock-step progression but, rather, a constructive process. Significant variance (74 percent) within age, across task situations in different content domains, is evident. At ages 11 and 12, the level of abstract thinking is the major change while at ages 13, 14, and 15, abstract thinking is a change in complexity of function and the changes in the capacity of working memory.[105]

Summary

The human brain, a three-pound organ directing man's life, contains hundreds of billions of cells interlinked through trillions of connections. The brain is the most complex entity challenging neuroscience, psychology, and education. To separate, investigate, and understand the brain and the mind, a Presidential proclamation initiated the 1990 Decade of the Brain.

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[105] Zopito Marini and Robbie Case, "The Development of Abstract Reasoning About the Physical and Social World," Child Development 65 (Feb. 1994), 147-59.

The brain's basic building block is the nerve cell (neuron) with axon and dendrite extensions. Beginning at conception, the neurons multiply at frantic rates to evolve into the gray matter that forms the cortex sheets on the surface of two cerebral hemispheres. White matter appears as the myelin enclosing the elongated axon regions. The third main form in the brain is the neuroglia matter that provide structural support and the metabolic energy support for the estimated 100 billion nerve cells in the human brain.

Chemical and electrical signals are transmitted throughout the brain. These signals are interdependent and meet at the synapse where chemical substances can alter the electrical conditions inside the brain cell and outside the cell membrane. The neuron receives excitatory and inhibitory signals simultaneously from many synapses. Other kinds of synapses regulate and release substances called neurotransmitters.[106]

Cell proliferation, under the control of regulatory genes (structure-building genes) establishes the brain's areas of specification. Genetic coding initiates developmental processes. The brain's final size and shape is determined during the nine months before birth.

Genetic coding does not contain all the information expressed in the final structure; as the environment changes, the brain changes. The fetal brain is perfectly adapted for life in the uterus; the infant brain is suited to the needs of

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[106] Sandra Ackerman, "Discovering the Brain," To the Institute of Medicine National Academy of Sciences (Washington, D.C.: National Academy Press, 1992).

the infant as the adolescent brain is suited to adolescence and the adult brain is suited to the needs of the adult. Transition through development is not incremental. Through specialization, the infant brain matures into the adolescent brain and into the adult brain. Final brain maturity takes place in the prefrontal lobes in the late teens or early adulthood.

Research in the areas of craniology, phrenoblysis, environmental impacts on the brain, and most recently, electroencephalographic activity, has been conducted to measure brain growth and developmental spurts. Most findings have concluded brain growth and spurts overlap the developmental stages postulated by Piaget, except during adolescence where a valley in brain growth spurt challenges the rationale for presenting abstract problem solving at this time.

Cognitive theory embodies the concepts developed across educational research and psychology and cognitive psychology and cognitive science domains. The cognitive revolution of the 1950s and 1960s emphasized learning and knowledge acquisition. Piaget viewed knowledge in four stages to parallel physical growth, ending with formal operations as the summit of intellectual growth. Vygotsky viewed knowledge acquisition as dependent upon culture and social interaction, with the "zone of proximal development" as the child's actual development level in reference to her potential developmental level.

These cognitive theories are relevant to instruction. The psychologies of subject matter can provide the basis for educational reform. Cognitive theory can provide the vision of what to teach, how to teach, and where to teach. A close relationship between cognitive theory and education and psychology can improve teaching and instruction.[107]

The emergence of formal thinking is highly significant and a relatively neglected aspect of development during puberty and adolescence. Cognitive change during puberty is a function of the individual attaining a new level of adaptation towards higher logic solving problems.[108] Piaget viewed cognitive development as a hierarchical process concerned with the consolidation of structures at progressively higher levels of abstractions. Piaget's treatment of formal operational thought is couched in an elegant system of sixteen logical operations and the tasks employed to measure the specific operations.[109] Researchers have investigated adolescents' performance on tasks requiring formal thinking. Although current research measures formal thinking beyond the original sixteen binary operations, the characteristics for combinatorial thinking, proportionality, hypothesis testing, and the ability to use higher-level formal thinking can be assessed through curriculum and hands-on tasks. Adolescents acquire formal thought at different rates and display a wide range of abilities when performing tasks requiring formal thinking as they transition from concrete

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[107] Richard E. Mayer, "Cognition and Instruction: Their Historic Meeting Within Educational Psychology," Journal of Educational Psychology 84 (1992): 405-412.

[108] Barnaby B. Barratt, "Training and Transfer in Combinatorial Problem Solving: The Development of Formal Reasoning During Early Adolescence," Developmental Psychology 11 (1975): 700-704.

[109] Edith D. Neimark, "A Preliminary Search for Formal Operations Structures," The Journal of Genetic Psychology 116 (1970): 223-232.

thinking to full formal thinking. Most adolescents seem to acquire formal operations first in combinatorial thinking, second in hypothetical-deductive reasoning, and third in proportionality.

Learning is a fragile and powerful interaction between genetics and environment. Human experience from eons past interacts with the experiences during a single person's lifetime. Genetics, development and experience dramatically shape the brain; the brain then actively shapes an individual's experiences and culture. In this context, parenting and teaching become the brain's facilitating agents.

CHAPTER III

METHODOLOGY

Restatement of the Purpose

The purpose of this study was to assess middle school students' cognitive developmental level by measuring their performance on Piagetian tasks requiring formal reasoning. The research findings will contribute empirical data to guide educators in lesson development and instructional practices that influence the transition from concrete to formal operations.

Research Design and Methodology

This study was conducted using three Piagetian-type paper-and-pencil tasks administered to middle school students in grades 6, 7, and 8. Three cognitive tasks--(1) testing combinatorial thinking, (2) testing proportional reasoning, and (3) testing hypothetical-deductive reasoning--were analyzed to answer the research questions. Descriptive statistics are presented to evaluate the mean rate of performance and standard deviation by grade level, gender and socio-economic status on each task. Percentages of subjects' performance at formal operations level, by grade, gender, and socio-economic status on the various tasks were analyzed and presented. A one-way ANOVA for each task and factorial ANOVA (between-subjects design) was performed to analyze the variance between the means.

Students in grades 6, 7, and 8 were administered the three Piagetian tasks during their regularly scheduled science class. Science classes were selected since the cognitive puzzles discuss science-related materials. During a 45-minute timed testing period, the students were asked to solve the three puzzles. Three participating middle schools, representing three different (i.e., high, middle, and low) socio-economic areas are located within the San Francisco Bay Area.

Population and Sample

The study was conducted within a Unified School District, located in Contra Costa County, California, with a population of 34,000. It is considered a suburban school district with some increasing urbanization and serves a diverse population, both ethnically and socio-economically. Nine middle schools serve the District and three were purposely selected to represent three socio-economic levels within the school district (i.e., high, middle, and low). Schools were selected on the basis of the percentage of students enrolled in Free and Reduced Lunch and Aid to Families with Dependent Children Programs. After selecting the three representative middle schools, a purposive sampling was done to access students currently enrolled in science class. The sample was determined by using 10% of each school's enrollment and dividing that figure by the average class size, i.e., n=(30). Using this procedure, each of the three middle schools yielded three classrooms to obtain the appropriate sample size. The sample selection, N=255, consisted of students at each grade level (6th, 7th, and 8th) from three science classes at each school site.

One participating middle school, located in Walnut Creek, California, represents the school with highest socio-economic status. The total school population is 1010, with only 1.6% of the students receiving Free and Reduced Lunch Program and only 0.8% Aid to Families with Dependent Children Program. Most family heads of households have professional "white collar" jobs and are college graduates or have attended some college. Other family heads of households are business owners and young entrepreneurs. This school has a very cosmopolitan and diverse student body representing forty different countries. The ethnic/racial makeup consists of 77% White, 17% Asian, 3% Hispanic, 2% Filipino, and 1% African American.

Student achievement in the high socio-economic status middle school is above average in all grades in standardized testing. In the California Assessment Program 6 and California Assessment Program 8 State Rank, these students performed in the 90th percentile in all academic areas over the last three years. In the Metropolitan Achievement Test 6, the students ranked in the 80th percentile over the past two years, when compared to students across the nation. The school has eight Mentor Teachers, two previous "Teacher of the Year" awards, and was recognized with the California Distinguished School Award granted to the top 5 percent of California schools. The technology class and sheltered core program have been recognized as "Program of Excellence."

Another participating middle school, located in Pittsburg, California, in the area called Bay Point, represents a culturally diverse population and the lowest socio-economic status in the District. The total school population is 755, with 57.8% of the students receiving Free and Reduced Lunch Program and 27.7% on Aid to Families with Dependent Children. Many family heads of households have non-professional "blue collar" jobs or work in the surrounding Delta and agricultural areas. The school enjoys a very ethnically diverse population with 43% White, 25% Hispanic, 18% African American, 8% Asian, 5% Filipino, and 1% Pacific Islander.

This middle school has a Chapter I Program and previously was a California Mathematics and English/Language Arts Demonstration Project School. Students perform below the average national percentile on Metropolitan Achievement Test 6. Over the last three years, the students performed between the 35th and 48th percentile in all academic areas when compared to students across the nation.

The last participating middle school is located in Concord, California, and represents a culturally diverse population with a middle socio-economic status. The total school population is 1008 with 22% of the students receiving the Free and Reduced Lunch Program and 8.1% on Aid to Families with Dependent Children.

This middle school received a Distinguished School Award in 1994. The school's staff has been recognized for its success in providing a caring and supportive student environment. One teacher has been recognized as District Teacher of the Year, another as Outstanding Teacher in America History, and another Mentor Teacher who is working on science integration. The orthopedically handicapped classes and computer programs at this middle school have been recognized as "Programs of Excellence." The school is organized into six interdisciplinary teams.

The school's cultural diversity is recognized and celebrated; the ethnic/racial makeup is 77% White, 13% Hispanic, 4% Asian, 3% African American, 2% Filipino, and 1% Pacific Islander. Test scores place this school in the top 30 percent of California schools nationally. Students scored in the 70th percentile in Metropolitan Achievement Test 6 testing, compared to all other U.S.A. schools in 1993.

This school clearly represents the middle socio-economic status school in the District. The family profile is a blend professionally, academically and culturally of the high socio-economic school and low socio-economic school. Demographics by socio-economic status show a relatively even distribution throughout the sample as represented by each class. (See Figure 1.)

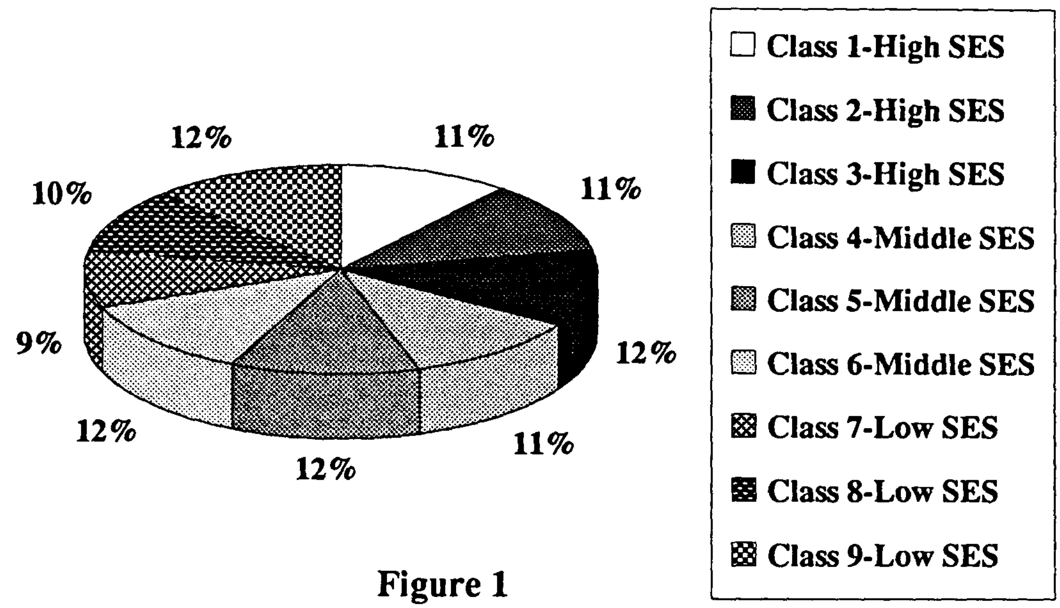

Figure 1
Demographics By Socio-Economic-Status
(255 Subjects Involved)

Description of Subjects

Middle school students in grades 6, 7, and 8 participated in the study (*N*=255); boys 53% (*N*=135) and girls 47% (*N*=120). The mean chronological age for the sample was 12.88 years (SD=1.01). Total student sample consisted of 29%, 6th grade (*n*=75); 34%, 7th grade (*n*=86); and 37%, 8th grade (*n*=94). The mean chronological age for each grade was: grade 6, 11.69 years (SD=0.49); grade 7, 12.86 years (SD=0.44); and grade 8, 13.84 years (SD=0.57). (See Figures 2, 3, and 4.)

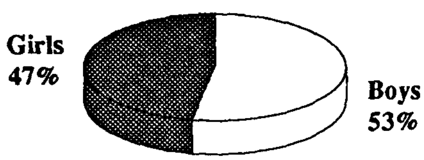

Figure 2
Demographics By Gender
(255 Subjects Involved)

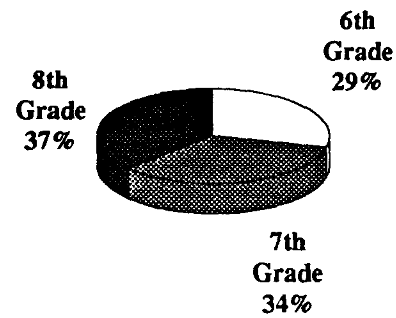

Figure 3
Demographics By Grade Level
(255 Subjects Involved)

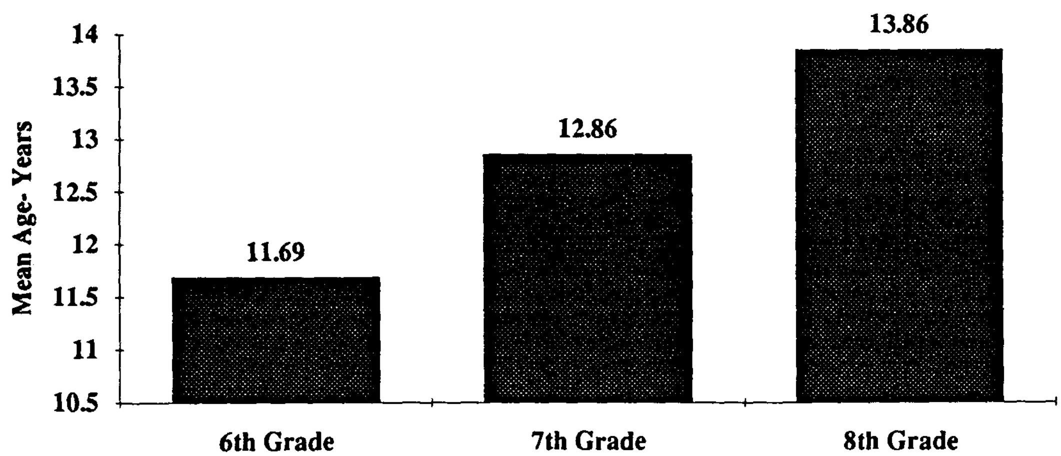

Figure 4
Demographics by Mean Age of Grade Level
(255 Subjects Involved)

The students were voluntary participants, selected by purposive sampling. Three classes, one at each grade level (6, 7, and 8) totaled the nine classes that participated. Classes 1, 2, and 3 represented the school in the high socio-economic status area. Class 1 (*n*=27) represents 11% of the total sample. Class 2 (*n*=27) represents 11% of the total sample. Class 3 (*n*=32) represents 12% of the total sample. The total student sample in this school (*N*=86) represents 34% of the study. Classes 4, 5, and 6 represent the school in the middle socio-economic status area. Class 4 (*n*=27) represents 11% of the total sample. Class 5 (*n*=32) represents 12% of the total sample. Class 6 (*n*=30) represents 12% of the total sample. The total student sample in this school (*N*=89) represents 35% of the study. Classes 7, 8, and 9 represent the school in the low socio-economic status area. Class 7 (*n*=22) represents 9% of the total sample. Class 8 (*n*=26) represents 10% of the total sample. Class 9 (*n*=32) represents 12% of the total sample. The total student sample in this school (*N*=80) represents 31% of the study.

The student sample was ethnically diverse: African American (*n*=23), 9%; American Indian (*n*=10), 4%; Asian (*n*=45), 18%; Hispanic (*n*=21), 8%; Pacific Islander (*n*=5), 2%; White (*n*=128), 50%; Other (*n*=19), 7%; and, missing (*n*=4), 2%. No attempt was made to test for significance of ethnic differences, since this study was not designed to provide such comparisons. (See Figure 5.)

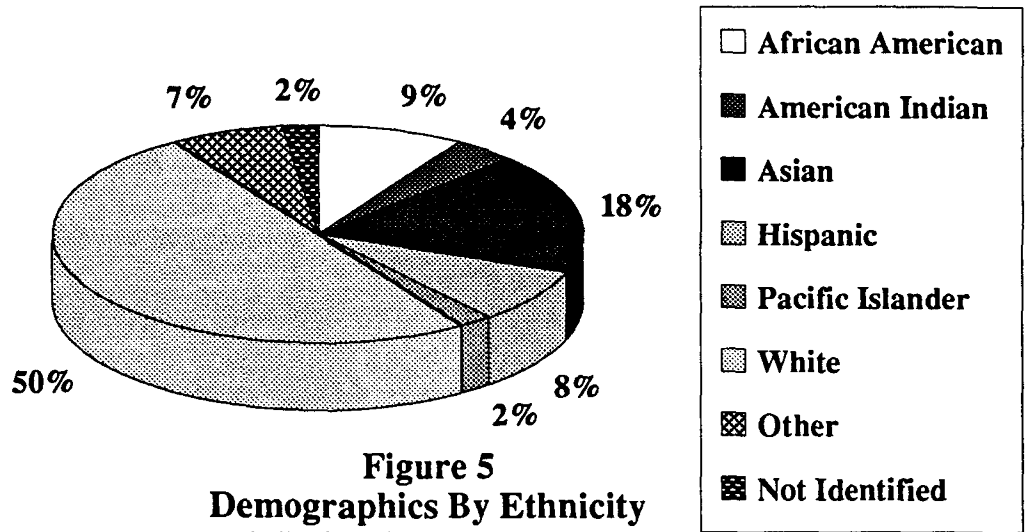

Figure 5
Demographics By Ethnicity
(255 Subjects Involved)

Instrumentation

The instruments used in the study were three Piagetian-type cognitive puzzles designed by Dr. Anton E. Lawson of Arizona State University while working on a Science Curriculum Improvement Study at the University of California at Berkeley. The project was supported by the National Science Foundation under Grant No. SED74-18950 from 1965 to 1975. The puzzles were developed to test the presence of formal operational thought. Three problem-solving puzzles were designed as a paper-and-pencil task.

The Algae Puzzle (see Appendix B) was designed to measure combinatorial thinking, a mark of formal operational thought. Subjects must demonstrate the capacity to understand and use the entire combinatorial system of sixteen binary operation or all possible combinations of "*n*" elements. The Frog Puzzle (see Appendix C) tests the subjects' ability to use proportional reasoning and to set up a ratio to solve the puzzle. Proportionally, using equivalent ratios is the method required to solve this puzzle and assess abstract formal thinking. The Mealworm Puzzle (see Appendix D) examines the subjects' ability to perceive a hypothetical situation, separate and control the variables, and make a decision. Hypothesis-testing involves thinking that uses deductive reasoning, reasoning from the general to the specific.

Combinatorial thinking, proportionality and hypotheses testing are all formal operational thinking characteristics. Formal operational thinking is considered the summit in cognitive development.[110]

Data Collection Procedures

An initial appointment with the School Superintendent to discuss the purpose, need, and instrumentation for the study resulted in the researcher being granted permission to conduct the study within the Unified School District. The Research and Evaluation District Administrator was contacted and the test instruments were forwarded to him after the research was approved by the

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[110] Barbel Inhelder and Jean Piaget, The Growth of Logical Thinking: From Childhood to Adolescence (New York: Basic, 1958).

University of San Francisco. The three middle school principals were contacted by the researcher, seeking permission to meet with their science teachers to conduct the study in their classrooms. The cognitive puzzles were sent ahead to the principals for preview, and discussed later. An information letter was prepared for the parents. The letter explained to the parents the confidentiality, research benefits, and how the information from the study would be used for research in education.

After the Science Department chairs reviewed the tasks, the researcher met with the Science Department Chair at each school ($n=3$) to explain the study and data collection procedure. Available classrooms were coordinated by the Principal and Science Department Chair at each middle school. Each school was coded by color and the puzzles randomly stapled in the following order: Random I--Algae, Frog, Mealworm; Random II--Frog, Mealworm, Algae; Random III--Mealworm, Algae, Frog. The three Piagetian cognitive puzzles designed as paper-and-pencil tasks were administered to students during regularly scheduled science classes in the three middle schools. During a forty-five-minute timed testing period, the students were asked to solve the three cognitive puzzles. Sixth, 7th, and 8th grade science classes were administered the tasks on Tuesday, Wednesday, and Thursday. Monday and Friday were purposely avoided due to possible fatigue occurring from the week-end activities and the end of the school week. The order in which classes were tested was determined by regular school scheduling.

A trained proctor distributed the three Piagetian cognitive puzzle tasks to the students. Students were instructed to write their name, sex, age, ethnic code, birthdate, and grade level on the cognitive puzzles. Student names were requested to make the task simulate a normal classroom assignment and to promote student buy-in and ownership for their performance. The proctor emphasized the exercises (puzzles) were not a test. The proctor read the directions for all three tasks and instructed the students when to begin. Care was taken to ensure that all subjects understood the nature of the tasks and supplemental verbal instructions were offered when necessary. Prior to testing it was determined that, once the instructions were read and questions clarified, no coaching would be allowed. However, during the testing it became apparent that several limited English-speaking students in each school needed additional language clarification to perform the tasks. During testing the proctor circulated, monitored, and checked to see if demographic information was on all tests. After forty-five minutes the testing materials were placed face down and collected individually by the proctor. The completed Piagetian tasks were placed in a manila envelope marked by grade and school, sealed, and returned to the researcher. Before scoring the tasks, students' names were removed from each task to ensure confidentiality.

Data Analysis Procedures

The Algae Puzzle (see Appendix B) showed four varieties of algae and asked the students to write each combination of algae they could find. Subjects did not need to know a mathematical formula for solving the puzzle. Rather, the subjects had to mentally manipulate the algae (Y, R, G, and B) to discover systematic strategies for generating an exhaustive set of combinations (permutations). This task required the subjects to use combinatorial thinking. The total number of possible combinations is sixteen, including the null or given set (Y, R, G, and B).

Scores for the Algae Puzzle were classified according to the subject's individual performance. The following numerical scores (0, 1, 2, 3, 4) were assigned for performance: Pre-operational (no attempt) = 0; Concrete (1 to 5 combinations) = 1; Transition (6 to 9 combinations) = 2; Formal I (10 to 14 combinations) = 3; and Formal II (15 to 16+ combinations, plus a metacognitive statement) = 4. Students were assigned a numerical score corresponding to a cognitive operation level.

The Frog Puzzle (see Appendix C) asked students how many frogs are in a pond, as determined by the amount of banded frogs. there are pictures of frogs but no other concrete visuals. This task requires the subjects to use proportional reasoning and to set up a ratio to solve the puzzle. Students must calculate what fraction of 72 frogs were banded frogs (12/72 = 1/6); then realize that 55 banded frogs = 1/6 of the total number of frogs; finally, 55 X 6 = 330, the total population of frogs.

Scores for the Frog Puzzle were classified according to performance with a numerical score (0, 1, 2, 3, or 4): Pre-operational (no attempt) = 0; Concrete (55 + 60 = 155 frogs) = 1; Transition (attempt at setting up a proportion but answered incorrectly) = 2; Formal I (answered 330 frogs with no equation) = 3; and, Formal II (answered 330 frogs plus symbolic equation and a metacognitive statement to explain the solution) = 4.

The Mealworm Puzzle (see Appendix D) showed four boxes of mealworms in dry or moist conditions and the effects of sunlight. Students must isolate and control the variables, setup a hypothesis, and answer what conditions mealworms favor. The correct box is "C."

Scores for the Mealworm Puzzle were classified according to performance, with a numerical score (0, 1, 2, 3, or 4): Pre-operational (no attempt) = 0; Concrete (an incorrect choice) = 1; Transition (an incorrect answer plus an explanation) = 2; Formal I (correct answer, "C," with no metacognitive statement) = 3; Formal II (correct answer, "C," plus a metacognitive statement supporting the answer) = 4.

Two trained raters were used to score the tasks. They were trained using the same model answers to control inter-rater reliability.

The assigned classifications representing cognitive development stages and the corresponding numeral given to each subject are categories evaluated and designated by the investigator, based on the design use by Gary and Rush in 1986.[111]

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[111] William Gary and Mary Lou Rush, "Formal Operations and Social Relativistic Thinking," Presented at the Sixteenth Annual Symposium of the Jean Piaget Society, Philadelphia, 1986 (Center for Applied Cognitive Science, The University of Toledo, Toledo, Ohio), EDRS Document Reproduction Service 270235.

The following statistical techniques were used to analyze each research question:

Research Question 1:

Are there significant grade differences (6th, 7th, and 8th) in cognitive development level for combinatorial thinking, proportionality, or hypothetical-deductive reasoning among middle school students?

Data Analysis for Question 1:

The frequency of each score (0-4) for each grade level will be presented, in Chapter IV, as a percent of the total. The means and standard deviations of the scores (0-4) for each task were calculated for each grade. Mean scores for all three tasks were analyzed, by grade level, using one-way analysis of variance, followed by post hoc paired comparisons. The effect size of each difference between means was determined using the formula M_1-M_2/SD (pooled).

Pearson Product Moment Correlations of score and age of subject were also run for each task to determine the magnitude and direction of the relationship of cognitive development level and age.

Research Question 2:

Are there significant gender differences (boy and girl) in cognitive development level for combinatorial thinking, proportionality, or hypothetical-deductive reasoning among middle school students?

Data Analysis for Question 2:

The frequency of each score (0-4) for each gender level will be presented, in Chapter IV, as a percent of the total. The means and standard deviations of the scores (0-4) for each task were calculated for each gender. Mean scores for all three tasks were analyzed, by gender, using independent groups Student t-tests (two-tailed tests). The effect size of each difference between means was determined using the formula M_1-M_2/SD (pooled).

Research Question 3:

Are there significant socio-economic status differences (low, medium, and high) in cognitive development level for combinatorial, proportionality, or hypothetical-deductive reasoning among middle school students?

Data Analysis for Question 3:

The frequency of each score (0-4) for each socio-economic status (SES) level will be presented, in Chapter IV, as a percent of the total. The means and standard deviations of the scores (0-4) for each task were calculated for each SES level. Mean scores for all three tasks were analyzed, by socio-economic level, using a one-way ANOVA, followed by post hoc paired comparisons. The effect size of each difference between means were determined using the formula M_1-M_2/SD (pooled).

Research Question 4:

What formal thinking ability emerges first--combinatorial (algae), proportionality (frog), or hypothetical-deductive reasoning (mealworm)--among middle school students?

Data Analysis for Question 4:

The percentage of scores representing formal thinking (3 or 4) for each task and grade level was calculated.

CHAPTER IV

FINDINGS

Introduction

The present study was designed to investigate the relationship between grade level, gender, and socio-economic status and performance on Piagetian tasks requiring formal operational thinking. The target population was middle school adolescents. Descriptive statistics will explain the results of the data analyses outlined in Chapter III for each research question. The Pearson Product Moment Correlation data will not be discussed since there were no significant correlations between grade level and sex on the tasks or between the three tasks.

Results of the Study

One third of the students received the tasks in Random Order 1 (algae, frog, mealworm), another third in Random Order 2 (frog, mealworm, algae), and the final third in Random Order 3 (mealworm, algae, frog). There were no significant differences related to order for any of the task means ($p=.36$, .17, and .28, respectively for combinatorial, proportionality, and hypothetical tasks). Therefore, order of presentation was not included in subsequent analyses.

The results will be presented by research question, with an additional section that describes a three-way ANOVA analysis for the combinatorial task.

Research Question 1:

Question 1 asked whether there were significant grade differences (6, 7, 8) in cognitive development level for combinatorial thinking, proportionality, or hypothetical deductive reasoning among middle school students. Table 1 presents the percent of students receiving each score (0 to 4) for each task by grade.

TABLE 1

PERCENT RECEIVING EACH SCORE BY GRADE

		Combinatorial				
	Score	0	1	2	3	4
Grade 6	N=75	6%	37%	15%	26%	15%
Grade 7	N=86	1%	48%	24%	27%	0%
Grade 8	N=94	4%	30%	19%	33%	14%
TOTALS	N=255	4%	38%	20%	29%	9%
		Proportionality				
	Score	0	1	2	3	4
Grade 6	N=75	5%	95%	0%	0%	0%
Grade 7	N=86	15%	83%	1%	0%	1%
Grade 8	N=94	16%	77%	5%	0%	2%
TOTALS	N=255	13%	84%	2%	0%	1%
		Hypothetical				
	Score	0	1	2	3	4
Grade 6	N=75	3%	36%	4%	2%	55%
Grade 7	N=86	7%	2%	51%	5%	35%
Grade 8	N=94	3%	12%	43%	5%	37%
TOTALS	N=255	4%	16%	34%	4%	42%

Percent of scores for combinatorial (algae task) show grades 6 and 8 performing almost equally. The percent of students receiving a score of 4 (Formal II) was highest in grade 6 (15%) and grade 8 (14%). No students in grade 7 received a score of 4. Students in grade 7 received the most scores (48%) at the Concrete level (1).

Performance on proportionality (frog task) show grades 6, 7, and 8 with most scores (84%) at the Concrete level (1). Grade 6 received no scores at Formal II; and grade 8 received 2 percent of the scores at Formal II (4). In grades 6, 7, and 8, no grade received scores at Formal I (3).

Scores for hypothetical (mealworm task) reasoning show grades 6, 7, and 8 with most scores (42%) at Formal II (4). Grade 6 received 55 percent of the scores at Formal II, the highest percentage by grade. Grade 7 received most scores at Transitional level (2), 51 percent. Grade 8 also received the most scores at Transitional level (2), 43 percent.

Performance by grade level changes across the three tasks. The mealworm task (hypothetical-deductive reasoning) showed the most scores overall (42%) of students performing at Formal II. Grade 7 scores consistently showed the lowest percentage of students performing at Formal II cognitive development level on any task. Grade 6 scored higher than grade 7 or 8 in combinatorial (algae task) and hypothetical-deductive reasoning (mealworm task) at the Formal II cognitive development level, and in proportionality (frog task), no scores were at the Formal I or Formal II cognitive development level. Grade 8 had the most scores

(2%) on proportionality (frog task) at Formal II, and grade 7 received 1 percent of scores at Formal II level. Performance on the frog task requiring proportional thinking appeared to be the most affected by grade.

Performance on proportionality (frog task) shows grades 6, 7, and 8 with the most scores (84%) at the Concrete level. Grade 6 received no scores at the Formal II level (4); grade 7 showed 1% at the Formal II level (4); and grade 8 showed 2 percent at the Formal II level (4). In grades 6, 7, and 8, no scores were at the Formal I level (3).

Table 2 shows the mean scores and standard deviations for the three tasks for all students and by grade level. The results of the one-way ANOVA (Grade 6, 7, 8) appear below the means. There was a significant grade level difference for the combinatorial task ($p=.02$). Tukey post hoc tests showed that the grade 8 mean score ($M=2.23$) was significantly higher than that of grade 7 ($M=1.77$) for this task ($p=.01$). The effect size of this significant difference was .45. The differences between grades 6 and 7 or between grades 6 and 8 were not statistically significant. There were no statistically significant grade level differences for either the proportionality (frog task) or hypothetical tasks (mealworm task).

TABLE 2

MEAN TASK SCORE BY GRADE

		Combinatorial		Proportionality		Hypothetical	
ALL	N=255	2.02	(1.10)	0.93	(0.50)	2.63	(1.28)
Grade 6	N=75	2.05	(1.23)	0.95	(0.23)	2.71	(1.49)
Grade 7	N=86	1.77	(0.86)	0.89	(0.51)	2.58	(1.19)
Grade 8	N=94	2.23	(1.14)	0.96	(0.64)	2.62	(1.19)
Grade Differences	F Ratio	4.01		0.38		0.20	
	p value	0.02*		0.68		0.82	

* Grade 8 mean score significantly higher than Grade 7 (Tukey, p=.01) --- Effect Size = .45; others not significantly different from one another.

Research Question 2:

Question 2 asked whether there were significant gender differences (boy, girl) in cognitive development level for combinatorial thinking, proportionality, or hypothetical-deductive reasoning among middle school students. Table 3 presents the percent of students receiving each score (0 to 4) for each task by gender.

Performance on combinatorial thinking (algae task), as measured by gender differences, appears to be only significant at the Formal II cognitive development level (4). Percentage of girls (13%) scoring 4 (Formal II) was more than twice as for boys (6%). Percent of boys' and girls' scores at the other cognitive development levels were almost equal across the cognitive development levels.

TABLE 3

PERCENT RECEIVING EACH SCORE BY GENDER

		Combinatorial				
	Score	0	1	2	3	4
Boys	N=135	4%	42%	21%	27%	6%
Girls	N=120	4%	34%	18%	31%	13%
TOTALS	N=255	4%	38%	20%	29%	9%
		Proportionality				
	Score	0	1	2	3	4
Boys	N=75	11%	85%	2%	0%	2%
Girls	N=86	14%	83%	2%	0%	1%
TOTALS	N=255	13%	84%	2%	0%	1%
		Hypothetical				
	Score	0	1	2	3	4
Boys	N=75	5%	14%	35%	4%	42%
Girls	N=86	3%	18%	33%	4%	42%
TOTALS	N=255	4%	16%	34%	4%	42%

Performance on proportionality (frog task) revealed most scores (84%) clustered at the concrete cognitive development level (1). Only 2 percent of scores was at the transition level (2), no scores were at Formal I cognitive level (3). Formal II cognitive level (4) received the lowest scores (1%). The percentage of boys performing above girls was 2 percent higher at the Concrete cognitive development level (1) and 1% higher at the Formal II cognitive development level (4).

Performance on hypothetical-deductive reasoning (mealworm task) showed nearly equal percentages across the scores for boys and girls. Boys' scores at the Preoperational and Transitional cognitive development level were 2 percent higher than girls' performance; girls' scores at the Concrete cognitive development level (1) were 4 percent higher than boys.

Overall boys' and girls' scores were equal at the Formal II cognitive development level (4). Scores for hypothetical-deductive reasoning showed 42 percent of students performing at the Formal II level; a higher score than for combinatorial or proportional thinking.

Table 4 shows the mean scores and standard deviations for the three tasks by all students and by gender. The results of the students' t-test (gender: boy, girl) appear below the means. There were no statistically significant differences between boys' and girls' mean scores for any of the tasks, although the difference for the combinatorial task approached significance (p=.07). The girls' mean score (M=2.15) was higher than the boys' mean score (M=1.90).

TABLE 4

MEAN TASK SCORE BY GENDER

		Combinatorial		Proportionality		Hypothetical	
ALL	N=255	2.02	(1.10)	0.93	(0.50)	2.63	(1.28)
Boys	N=75	1.90	(1.04)	0.96	(0.52)	2.63	(1.29)
Girls	N=86	2.15	(1.16)	0.91	(0.48)	2.63	(1.28)
Gender Differences	t-test	1.79		0.75		0.02	
	p value	0.07		0.45		0.98	

Research Question 3:

Question 3 asked whether there were significant socio-economic status differences (high, middle, low) in cognitive development level for combinatorial thinking, proportionality, or hypothetical-deductive reasoning among middle school students. Table 5 presents the percent of students receiving each score (0 to 4) for each task by socio-economic status (SES).

TABLE 5

PERCENT RECEIVING EACH SCORE BY SOCIO-ECONOMIC STATUS (SES)

		Combinatorial				
	Score	0	1	2	3	4
High SES	N=86	0%	17%	26%	37%	20%
Middle SES	N=89	4%	46%	17%	28%	5%
Low SES	N=80	8%	51%	16%	21%	4%
TOTALS	N=255	4%	38%	20%	29%	9%
		Proportionality				
	Score	0	1	2	3	4
High SES	N=86	17%	77%	5%	0%	1%
Middle SES	N=89	8%	88%	2%	0%	2%
Low SES	N=80	12%	88%	0%	0%	0%
TOTALS	N=255	13%	84%	2%	0%	1%
		Hypothetical				
	Score	0	1	2	3	4
High SES	N=86	1%	29%	26%	6%	38%
Middle SES	N=89	4%	16%	33%	3%	44%
Low SES	N=80	7%	1%	45%	4%	43%
TOTALS	N=255	4%	16%	34%	4%	42%

Performance by SES level on combinatorial thinking (algae task) showed the high SES students scoring with the highest (20%) at the Formal II (4) cognitive development level. No students scored at the Preoperational level. The students in the middle SES area scored the highest (46%) at the Concrete level (1). Only 5 percent of the students in the middle SES area performed at Formal II. The students in the low SES area performed very close to students in the middle SES area; students scored the highest (51%) at the Concrete level and only 4 percent performed at Formal II (4).

Performance by SES level on the proportionality (frog task) shows very similar scores across the three SES areas except students in the middle SES area scored highest (2%) at the Formal II level. All students scored the highest percent at the Concrete level (1) in all SES areas. No students performed at the Formal I level and students in the low SES area only scored at the Preoperational and Concrete cognitive levels.

Performance by SES on the hypothetical-deductive (mealworm task) showed the highest percentage of scores at Formal II. Students in the middle SES and the low SES scored highest at Formal II. Few scores were clustered at the Preoperational level (0), but students in the high SES had 1 percent of the scores at Preoperational level. Students in the low SES had fewest scores at Preoperational, Concrete, and Formal I. Most student scores in the low SES were at the Transition and Formal II levels.

Table 6 shows the mean scores and standard deviations for the three tasks for all students and by SES. The results of the one-way ANOVA (SES: high, middle, low) appear below the means. There was a significant SES difference for the combinatorial task (p=<001). Tukey post hoc tests showed that the high SES students' mean score (M=2.59) was significantly higher than that of both middle SES (M=1.82) and low SES (M=1.62) students' mean scores for this task (p=<.001 in both cases). The effect sizes were .77 and .97, respectively. Middle and low SES students' mean scores were not significantly different from one another. There were no statistically significant SES differences for either the proportionality or hypothetical tasks.

TABLE 6

MEAN TASK SCORE BY SOCIO-ECONOMIC STATUS (SES)

		Combinatorial		Proportionality		Hypothetical	
ALL	N=255	2.02	(1.10)	0.93	(0.50)	2.63	(1.28)
High SES	N=86	2.59	(1.00)	0.91	(0.57)	2.51	(1.30)
Middle SES	N=89	1.82	(1.04)	1.01	(0.55)	2.66	(1.30)
Low SES	N=80	1.62	(1.02)	0.87	(0.33)	2.72	(1.24)
SES Differences	F Ratio	21.24		1.74		0.61	
	p value	<.001*		0.18		0.54	

* High SES stuents' mean score significantly higher than both Middle and Low SES (Tukey, p<.001) --- Effect Size = .77 and .97 respectively; Middle and Low SES not significantly different from one another.

Research Question 4:

Question 4 asked what formal thinking ability emerges first--combinatorial (algae), proportionality (frog), or hypothetical-deductive reasoning (mealworm)--

among middle school students. Table 2 above showed the means for the three tasks by grade. Figure 1 shows these same data in graph form. For all grades the relationship was identical. The students in each grade (and when combined) received the highest mean scores for the hypothetical-deductive reasoning (mealworm) task, next highest mean scores for the combinatorial (algae) task, and the lowest mean scores for the proportionality (frog) task.

Grade 8 performed above the mean score and grade 7 performed below the mean score on each task (and when combined). Grade 6 performed near the mean score or above on each task (and when combined) and higher on all tasks than grade 7.

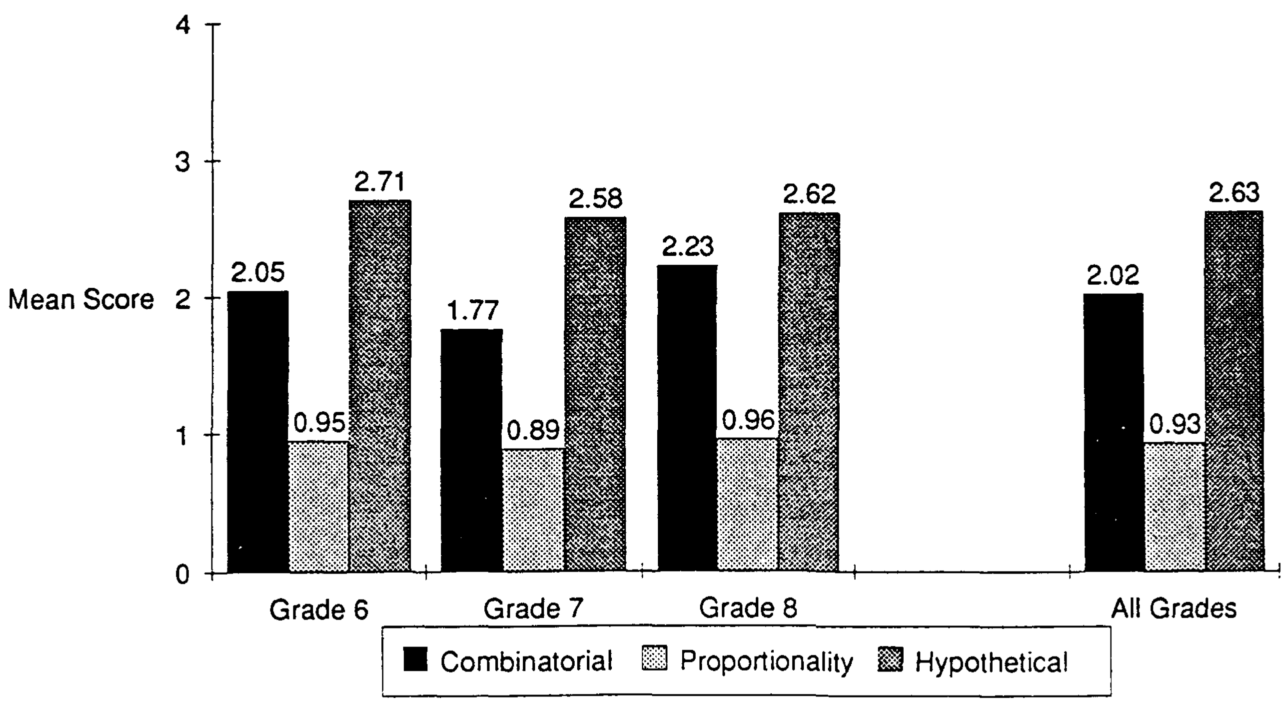

Figure 6
Mean Task Score by Grade

Factorial ANOVA:

A Grade (6, 7, 8) x Gender (boys, girls) X SES (high, middle, low) factorial ANOVA was performed for the task that was shown to be a significant source of variance in the one-way ANOVAs (the combinatorial (algae) task). The source table for this 3 x 2 x 3 ANOVA is presented in Table 7. There was a significant main effect of grade (p=.05) and SES (p=<.001). The Grade x SES interaction was significant (p=.03). Table 7 presents the means for the significant interaction and the three-way ANOVA table for the combinatorial task. Figure 6 shows the interaction graphically. The mean scores for grade level vary as you move from one to another level of SES. For example, 6th graders score higher than 7th, except for those in the low SES group.

TABLE 7

MEAN SCORE AND ANOVA SOURCE TABLE FOR COMBINATORIAL TASK BY GRADE, GENDER, AND SOCIO-ECONOMIC STATUS (SES)

	High SES	Middle SES	Low SES
Grade 6	2.59	2.19	1.23
Grade 7	2.33	1.54	1.46
Grade 8	2.81	1.80	2.03

	Sum-of-Squares	df	Mean-Square	F-Ratio	p
GRADE	5.98	2	2.99	3.02	.05
GENDER	1.01	1	1.01	1.02	.31
SES	37.45	2	18.73	18.88	<.001
GRADExGENDER	2.07	2	1.04	1.05	.35
GRADExSES	10.74	4	2.68	2.71	.03
GENDERxSES	4.14	2	2.07	2.09	.13
GRADExGENDERxSES	1.96	4	0.49	0.49	.74
ERROR	235.08	237	0.99		

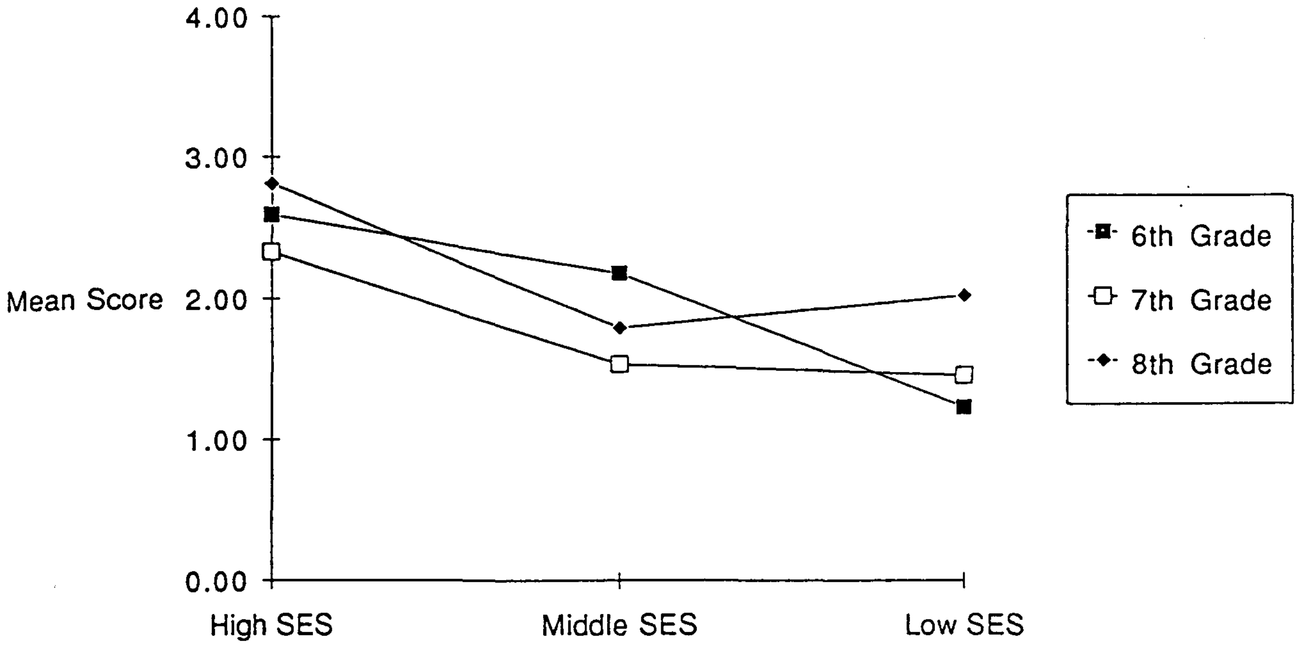

Figure 7
Mean Algae Scores -- Grade x Socio-Economic Status Interaction
(N=255)

Qualitative Evaluation of Metacognitive Statements

The qualitative aspect of the data analysis involved assessing the metacognitive statements. Metacognitive statements were evaluated for each cognitive puzzle (algae, frog, and mealworm task). Students were asked to justify their answers on each task. The purpose for the probing answers was to determine if the student used metacognitive strategies to figure out the tasks.

Subjects could not receive a Formal II score (4) on any task unless a correct answer was accompanied by a descriptive metacognitive statement to support their answer. Awarding one point for a metacognitive statement was a subjective decision based on specific criteria the subjects had to mention in their justification. A student could get a score of 1 for a metacognitive statement even if the answer to the task was incorrect. A point was not awarded if the statement was not metacognitive in nature.

To be classified as an acceptable justification, the metacognitive statement for combinatorial reasoning (algae task) had to give evidence of starting with the given set (Y, R, G, B) and proceeding with some kind of systematic pairing of each algae to make up unduplicated combinations. Reversals were not considered a new combination. To be classified as an acceptable justification, the metacognition statement for proportionality (frog task) had to show evidence and rationale for manipulating the numerals. Students were given credit for a wrong answer if they simply mentioned the strategy or reason for their computation. To be classified as an acceptable justification, the metacognitive statement for hypothetical (mealworm task) had to give some evidence of determining the variables sun, dry, and wet, and why the mealworms were attracted to any variable. Students were given credit for a wrong answer if they could reasonably discuss, isolate, and separate the variables.

Overall, most students were given credit for their metacognitive statement if the justification gave evidence of the students' thinking process. It would be difficult to challenge a thinking process as not being sound judgment; if the thinking is accurate in the students' perception, then it is real for that particular student.

Absurd responses, or justifications that said, "I just did it," or "I just added the numbers," or "I just looked at the mealworm boxes" were not considered passing responses. Another example would be, "I just knew the answer."

The metacognitive statements (see Appendix E) clearly reflected cognitive developmental levels. As the students moved from Preoperational to Concrete into Transition, next to Formal I and finally to Formal II, the metacognitive statements became richer in detail, content and quality of expression. When a metacognitive statement said, "I figured out at once how to do it," the student had almost always answered the question incorrectly. Rather than using critical thinking, the response almost seemed instinctive. There was no evidence of presolution thinking. When students did respond correctly and gave an accurate justification, some of the elements of the lower levels of cognition were still evident. It appears that Preoperational and Concrete thinkers cannot distinguish between an absurd or sensible solution, whereas the students at the higher levels can evaluate their thinking processes. Samples of typical metacognitive responses are included in Appendix E.

Summary

The purpose of this study was to assess the cognitive level of middle school while students performing formal Piagetian tasks. The research questions asked if there were changes in performance in thinking level as measured by grade level, gender, and socio-economic status. These three tasks measured three levels of formal operational thinking: combinatorial reasoning (algae puzzle), hypothetical-deductive reasoning (mealworm puzzle), and proportional reasoning (frog puzzle). The last research question sought to answer which type of formal reasoning emerged first: combinatorial, hypothetical, or proportionality.

The assessment showed that generally performance increased by grade level on all tasks. The mean scores showed 8th grade students always performed above 6th grade students on all three tasks. Seventh grade students' performance was the lowest and below the mean on all tasks. There are many speculations about this phenomena which will be discussed in Chapter V.

Hypothetical-deductive reasoning (mealworm puzzle) was the easiest task overall for the students. All grade levels scored above the mean and grade 7 showed best performance on this task.

Combinatorial reasoning (algae puzzle) showed the second level of difficulty for middle school students in this study. Grades 6 and 8 were above the mean and grade 7 slightly below.

Proportionality (frog puzzle) was the most difficult task for all students. All scores were below the mean. Most students in grade 6 performed at the Concrete level (1) and no 6th grade students performed at Formal I (3) or Formal II (4). In 7th grade, 1 percent scored at Formal II, and in 8th grade, 2 percent scored at Formal II on proportionality.

Performance by gender on all three tasks was the focus of the second research question. There were no significant gender differences between boys' and girls' mean scores on any task. The girls' mean score for the combinatorial task was higher than for boys.

Socio-economic status showed no significant SES differences for either the proportionality or hypothetical tasks. There was a significant SES difference for the combinatorial task ($p=<.001$). The high SES students' mean scores ($M=2.59$) was significantly higher than both middle SES ($M=1.82$) and low SES ($M=1.62$) students' mean scores.

In this present study formal operational thinking appears to emerge in the following order: (1) hypothetical-deductive reasoning; (2) combinatorial thinking; and, (3) proportionality. Statistically, this was evident on all tasks through all grades. These findings are in contrast to the normally predicted order of acquisition for formal reasoning where combinatorial thinking emerges first, hypothetical-deductive reasoning emerges second, and proportionality emerges last.

CHAPTER V

SUMMARY, CONCLUSIONS, IMPLICATIONS, AND RECOMMENDATIONS

Introduction

Middle school students have been recognized as the greatest potential "at-risk" school population in the United States.[112] During the middle years, students in grades 6, 7, and 8 encompass a wide range of physical, intellectual, psychological, and social development. Youth at risk have the greatest potential of becoming school dropouts. The academic, social and emotional concerns of this school population have been a major concern of the educational community.[113]

Schools should provide young adolescents with stability, security, and an academic program that reconciles their physical and emotional development with their cognitive development. Without the proper awareness of middle school

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[112] Education USA 27 (1985): 347.

[113] Bill Honig, Caught in the Middle Educational Reform for Young Adolescents in California Public Schools (California State Department of Education, 1987): 65; Jo Sue Whisler, "Young Adolescents and Middle Education: A Review of Current Issues, Concerns, and Recommendations," Mid-Continent Regional Educational Laboratory, sponsored by: Office of Educational Research and Improvement (ED), Washington, DC (Aurora, Colorado, 1990), ERIC Document Reproduction Service ED 346960; Carnegie Council on Adolescent Development, Turning Points (New York, New York: Carnegie Corporation of New York, 1989).

students' needs, educational programs may ultimately be a catalyst for students leaving school prior to graduation.

The purpose of this study was to investigate the middle school students' cognitive developmental level by measuring their performance on Piagetian tasks requiring formal reasoning. The research findings contribute empirical data to guide educators in curriculum and lesson development and instructional strategies that influence the transition from concrete to formal operational thought.

Summary

This study was conducted using three Piagetian-type paper-and-pencil tasks administered to middle school students in grades 6, 7, and 8 representing low, middle, and high socio-economic status areas. Three public middle schools within a unified school district in the San Francisco Bay Area participated in the research study. The puzzles were designed by Dr. Anton E. Lawson of Arizona State University.[114] Three cognitive tasks testing (1) combinatorial thinking (algae puzzle), (2) proportional reasoning (frog puzzle), and (3) hypothetical-deductive reasoning (mealworm puzzle) were administered to students in a forty-five-minute testing period. Students' performance by grade, gender, and socio-economic status were analyzed to answer the four research questions. The overall purpose of the investigation was to (1) determine the percent of middle school students using formal operational thinking when performing the various tasks, and (2) what

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[114] Anton E. Lawson, Ph.D., Science Curriculum Improvement Study, Grant No. SED74-18950, University of California, Berkeley, California (1965-1975).

formal thinking ability emerges first--combinatorial, proportionality, or hypothetical-deductive reasoning--in middle school students.

Extensive literature was presented in Chapter II under the three categories of (1) brain development and research, (2) psychological learning theory and research, and (3) characteristics of cognitive ability of adolescent middle school students when performing formal operational tasks.

The cognitive revolution of the 1950s and 1960s emphasized learning and knowledge acquisition. Jean Piaget viewed knowledge in four stages to parallel physical growth. Vygotsky viewed knowledge acquisition as dependent upon culture and social interaction with the "zone of proximal development" as the actual development level in reference to a child's potential developmental level. Gardner identified the "seven intelligences," some of which are possessed by all, in his Multiple Intelligence Theory.

Although it was generally assumed from Piaget's work that children move automatically through the cognitive developmental stages of sensori-motor, preoperational, concrete, and formal operations, later investigation showed the stages were open to question. The period of formal operations, thought to emerge around age 12, in particular became a target for extensive research. Because the formal operations cognitive stage focused on the growing child's ability to replace concrete objects with more sophisticated abstract thinking, the ambiguity surrounding this type of thinking in reference to the child's performance has continued to be an ongoing subject of research.

Piagetian stage theory has been studied in relation to brain growth. Most brain growth spurts align with Piaget's cognitive development theory except for the formal operational stage. In most brain growth studies, the ages between 12 and 14 show a decline in brain growth activity as measured by skull size and electroencephalogram. Although the frontal lobes, the brain's "top executive" or "orchestrator," are continuing to develop and refine attention, abstract thinking, and working memory during this period of adolescence, it is suggested in the literature that, because of the valley in brain growth, new concepts requiring abstract thinking, particularly in the areas of proportional reasoning, should be avoided during the middle school grades.

Conclusions

Middle school students are capable of using combinatorial thinking when classifying objects and combining them in exhaustive sets. Adolescents have the ability to perceive a situation, isolate and control the variables, and set up a hypothesis. Proportional reasoning appears to be beyond the capabilities of most middle school students. This type of formal thinking is achieved through instruction, building awareness and experience-based lessons.

Interpreting the first research question investigating middle school students' (grades 6, 7, 8) performance on tasks requiring formal operational thinking (combinatorial, proportionality and hypothetical-deductive reasoning) revealed students in grade 7 to score the lowest overall. This performance may be attributed to the social, emotional, and physical characteristics of 7th graders.

Seventh-grade students are beginning to test their decision-making powers and are more likely to challenge parental and teacher authority than 6th graders. Students in grade 7 seem to be less focused than students in grades 6 and 8. Seventh-grade students are more independent than sixth-grade students, yet they are more involved with the physical changes of puberty than students in grade 8 whose physical maturation is beginning to taper off by age 14.[115] The combinatorial task required time and patience to discover all the possible algae combinations. Seventh graders display less patience when given a new challenge in contrast to 6th graders who persevere through a new task and 8th graders who accept the challenge. Many adolescents avoid thinking critically or approach formal tasks with great tenacity.[116] Many 7th graders prefer to work on familiar tasks that are concrete, but many lessons given require abstract thinking.

Performance by grade on hypothetical task (mealworm) showed the highest percent (42%) of all grades receiving Formal II (4) scores and the lowest perecent (4%) of all grades receiving Preoperational (1) scores. This performance seems to indicate that most subjects have moved beyond the preoperational thinking level and can perform higher operations associated with formal thinking, namely, the process of separating and controlling variables which are necessary to solve the

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[115] Hershel D. Thornburg, "The Counselor's Impact on Middle Grade Students," The School Counselor, 33, no. 3 (1986): 170-177.

[116] Roger W. Bybee and Robert B. Sund, Piaget for Educators (Columbus, Ohio: Charles E. Merrill Publishing Company, 1982).

mealworm puzzle. This puzzle was very visual which may have helped the students determine the correct answer. The familiar content of the mealworm puzzle could have also increased performance.[117] Grade 6 students received a large percent of scores at the Concrete (1) and the highest percent of scores at Formal II (4) on the mealworm puzzle which indicates that, if 6th graders could perform beyond concrete thinking, they could determine the correct answer and could support that answer metacognitively. Grade 7 students received the highest percentage of scores at the Transition level (2) on the mealworm puzzle which appears to be a valid indicator of where these students are physically, emotional, socially, and cognitively.[118] Students in grade 7 would benefit from lessons containing both concrete and formal elements. Practice on familiar tasks gives cognitive security which helps move students to mastery. It appears that 7th-grade students may benefit from lessons that give them emotional security during adolescence. Seventh-grade students like to work in pairs and small groups where they can socialize while they discuss and learn.

The most difficult task for all grade levels required the subjects to use proportionality (frog task). This task, as indicated by Lowery, clearly shows that

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[117] Marcia C. Linn, Cathy Clement, and Steven Pulos, "Is It Formal if Its Not Physics? (The Influences of Content on Formal Reasoning), Journal of Research in Science Teaching 20 (Nov. 1983): 755-770.

[118] Hershel D. Thornburg, "The Counselor's Impact on Middle Grade Students," The School Counselor, 33, no. 3 (1986): 170-177.

most students in grades 6, 7, and 8 function at the Concrete level mathematically.[119] The overall percent (84%) of scores was at the Concrete level, indicating that students could not set up a ratio or proportion. Sixth-grade students who received 95 percent of their scores at the Concrete level (1) and seventh-grade students who received 83 percent of their scores at the Concrete level (1) may not have yet been exposed to ratio and proportion in mathematics and clearly could not figure out the process without prior instruction or experience. No student in grade 6 received a Formal I or Formal II score, indicating they did not understand or have experience with proportions and could not set up a ratio formula. In proportional reasoning, no scores fell at the Formal I level. A score at the Formal I level in proportionality would indicate that the subjects had attempted to set up a ratio but could not justify their strategy with a metacognitive statement. It appears if subjects could successfully set up the ratio or proportion, they knew how to compute the answer and justify that answer metacognitively. The same is true at grade 7 where 1 percent of the students scored Formal II. Grade 8 students received 2 percent of their scores at Formal II and, like grade 7 students, no scores at Formal I.

Proportions are usually presented as pre-algebra curriculum. Yet algebra as middle school curriculum, has come under attack in recent years. Algebra is

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[119] Lawrence F. Lowery, Thinking and Learning Matching Developmental Stages with Curriculum and Instruction (Pacific Grove, California: Midwest Publications, 1988).

thought to be too abstract for most middle school students.[120] Even if 8th-grade students can learn to manipulate the algebraic equations, they cannot apply the equations to real-life situations. Although algebra continues to be taught in middle schools, it is recommended to be more appropriate curriculum for grade 9.[121] More practice in proportionality may be beneficial before presenting algebra.

Interpretation of the scores for Research Question 2, asking if there are significant differences in cognitive development as measured by gender, showed boys had a higher percentage of scores at the Concrete (1) and Transition (2) level and girls had a higher percentage of scores at Formal I and twice the percent of scores at Formal II in combinatorial thinking. Maturation could play a factor in the high performance of boys at the Concrete level. Physiologically, boys are behind girls about two years which could also delay their cognitive development leaving them behind in some skills.[122] The algae task for combinatorial thinking took patience to work through all the permutations; perhaps (and most likely) this is not the style for many middle school boys.

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[120] Honig, Bill, Caught in the Middle Educational Reform for Young Adolescents in California Public Schools (California State Department of Education, Sacramento, California: 1987): 65.

[121] Lawrence F. Lowery, Thinking and Learning Matching Developmental Stages with Curriculum and Instruction (Pacific Grove, California: Midwest Publications, 1988).

[122] Hershel D. Thornburg, "The Counselor's Impact on Middle Grade Students," The School Counselor, 33, no. 3 (1986): 170-177.

Proportionality shows the boys' scores ahead of girls at most levels, especially at the Formal II (girls, 1%; boys, 2%). Research has shown a higher correlation between problem solving and arithmetic concepts for boys and a higher correlation in reading and problem solving for girls.[123] Although boys have outperformed girls in mathematics and science, recent research has shown this to be a factor of gender expectation rather than capability. The gap in gender performance seems to be decreasing through building awareness of gender expectation and student achievement. Cognitively and developmentally, most middle school students were at the Concrete level in proportional thinking. Gender differences were not statistically significant.

Scores on hypothetical thinking were nearly equal for boys and girls. This was a very visual task, showing the highest percentage of scores at the Formal II level (4), and the next highest percentage of scores at the Transition level (2). It can be assumed that this task was developmentally appropriate for middle school students regardless of gender. The content and variables were familiar to the students which increased performance. Generally, students perform better when lessons have visual input. Pictures add clarity and dispel abstractions.

Interpretation of Research Question 3, asking if there are significant differences in cognitive development as measured by socio-economic status areas, indicates that the low SES had a significantly lower percentage of scores in

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[123] Edith D. Neimark, "A Preliminary Search for Formal Operations Structures," The Journal of Genetic Psychology 116 (1970): 223-232.

combinatorial thinking at the Formal II level than did high SES students. Most of the scores (38%) for the low SES students fell at Concrete. Although the scores in the middle SES school were also lower than the high SES school, fewer students performed at the Concrete level. Factors such as a higher percentage of new immigrants, higher enrollment of limited English-speaking students, fewer opportunitieso participate in extracurricular activities due to limited income, poor diet, and the lack of literacy could all slow down the process of cognitively moving toward formal thinking.[124] It has been suggested that there is less continuity between the home and school environment in families with lower levels of schooling which prevail in lower socio-economic status areas.[125] These factors may also be the reason that there were no scores at Transition, Formal I, and Formal II for proportionality among the lower SES students. Although basic mathematic computations are not usually impacted by language, applied problems rely heavily on good command of reading and language skills. The students' ability to interpret the task's subject matter and then write a metacognitive strategy depends heavily upon the language in which the task is presented.

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[124] Anthony D. Pellegrini, "Some Questions about the Basic Tenets of Brain Periodization Research," Journal of Instructional Psychology 11, no. 3 (1984): 165-169.

[125] Lorene C. Quay, "Interactions of Stimulus Materials, Age, and SES in the Assessment of Cognitive Abilities," Journal of Applied Developmental Psychology 10, no.3 (July-Sept 1989): 401-409.

Performance on hypothetical thinking shows the scores relatively equal across the socio-economic status areas on Formal I (3) and Formal II (4). The most interesting cluster of scores (29%) for high SES is at Concrete, in relation to low SES scores (1%). At the Formal II level, scores for low SES (43%) were above high SES (38%) and almost equal to middle SES (44%). The visual nature of the mealworm task would not be impacted by language or experience which may be an answer for the high performance of low SES students. The high percentage of scores at the Concrete level for high SES students is difficult to speculate, although many high SES students may spend more time with books, technology, and organized sports and found the mealworm puzzle a low stimulus activity. High SES students may spend more time in structured activities and less time in just exploring and participating in hands-on activities like building or working outside. Unplanned time can encourage mental meandering and discovery. Low SES students may have found the pictures enough stimulation to engage them in the mealworm puzzle, and high SES students may have needed more task stimulus. Perhaps low SES students had more patience to observe and mentally manipulate the mealworm puzzle without the need for added stimulation.

The last interpretation discusses Research Question 4, asking what formal thinking ability emerges first [combinatorial (algae), proportionality (frog), or hypothetical-deductive reasoning (mealworm)] among middle school students. Performance on hypothetical (mealworm task) was consistently above the mean score. This task appeared to be the most developmentally appropriate for all grades, gender, and socio-economic status areas. This task highlights graphic importance and content familiarity.[126] Students could access prior knowledge and experience to separate and control the variables and make a decision, which also made it easier for students to evaluate their strategy and write a metacognitive statement. Reading and language skills did not greatly influence performance since the students could listen to the directions and look at the pictures.

In the present investigation, hypothetical-deductive reasoning appears to be the first type of formal thinking to develop during the middle school years as determined by student performance. Research by Barratt, Lowery, Mattheis, et al., Roberge, and Neimark found combinatorial thinking to be the first acquisition in formal thinking.[127] The ability to classify and reclassify marks the attainment of concrete thinking and the beginning of combinatorial thinking. Piaget

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[126] Marcia C. Linn, Cathy Clement, and Steven Pulos, "Is It Formal if Its Not Physics? (The Influences of Content on Formal Reasoning), Journal of Research in Science Teaching 20 (Nov. 1983): 755-770.

[127] Barnaby B. Barratt, "Training and Transfer in Combinatorial Problem Solving: The Development of Formal Reasoning During Early Adolescence," Developmental Psychology 11 (1975): 700-704; Lawrence F. Lowery, Thinking and Learning Matching Developmental Stages with Curriculum and Instruction (Pacific Grove, California: Midwest Publications, 1988); Floyd E. Mattheis, William E. Spooner, Charles R. Coble, Shigekazu Takemura and Shinji Matsumoto, Katsunobu Matsumoto, Atsushi Yoshida, "A Study of the Logical Thinking Skills and Integrated Process Skills of Junior High Students in North Carolina and Japan," Science Education 76, no. 2 (1992): 211-222; James J. Roberge and Barbara K. Flexer, "Further Examination of Formal Operational Reasoning Abilities," Child Development, 50 (June 1979), 478-484; Edith D. Neimark, "A Preliminary Search for Formal Operations Structures," The Journal of Genetic Psychology 116 (1970): 223-232.

suggested this skills forms at the onset of formal thinking. In most research formal skill attainment normally progresses from combinatorial to hypothetical thinking and last to proportionality. The high percentage of students performing at Formal II (4) on hypothetical thinking impacted the overal performance on combinatorial thinking. For various unpredictable reasons, the mealworm puzzle was easier than the algae puzzle for all students.

Performance on the combinatorial (algae task) was above the mean score (2.02) overall for all grades; highest mean scores (2.63) were on hypothetical (mealworm task). Two factors may have been responsible for a lower performance on the combinatorial task. To make all the possible combinations (16), students had to systematically develop the permutations. Some students began and then stopped; other students made too many combinations and just reversed the letters while others could not cognitively ignore the subject matter of the crabs. This task took perseverance, patience, and the ability to ignore the story of the crabs' appetite. With maturity, the students should be able to perform this task quite well when they can stay with a task, ignore the unimportant details and develop a systematic approach. It seems very possible that performance would have been higher in combinatorial thinking if the students could have actually manipulated the algae and recorded at the same time. Again, the content and abstraction of the subject matter appears too difficult for many middle school students.

Performance on proportionality (frog task) was the poorest overall and below the mean (0.93). Most middle school students appear to be functioning mathematically at Concrete development level with some movement into Transition development level. Setting up a ratio or proportion is an abstrat pre-algebra process which appears to be beyond the cognitive level of students in grade 6. Only 1 percent of students at grade 7 and 2 percent at grade 8 could perform the task at Formal II. No scores fell at Formal I, indicating that if students had experience with setting up a ratio, they could metacognitively justify their strategy. Some students in grades 7 and 8 have been enrolled in algebra which probably helped these students solve the frog puzzle; this proportion is unknown. Some middle school students will always be capable of algebra regardless of whether the California State Department of Education recognizes it as appropriate curriculum for these students.

Setting up a ratio seems to be a learned process. It does not appear that general mathematics knowledge can be easily applied to setting up a ratio or understanding proportionality. Many students asked questions because they were confused about the frogs, bands, and trips to the pond. Others just added the available numbers. Many students expressed intuitively that they did not think they should just add the numbers, but they did not know any other way to proceed. Those students decided there was not enough information to answer the frog puzzle. The few students who used a ratio did the process quickly, and their metacognitive statements supported their strategy.

The data gleaned from this research suggests if a task is cognitively appropriate, most students will perform at the mean or above. Décalagé occur when one content domain is more difficult than another.[128] The more abstract and tedious a task becomes, performance goes down, especially in grade 7. Visual enhancement plays an important part in performance. Abstract problem solving using proportionality appears to be well beyond the cognitive ability of 6th graders, and most 7th and 8th graders. Adolescents can adequately assess the imperative stimuli when performing tasks, but they cannot suppress the processing of irrelevant information on tasks like the algae puzzle.[129] Middle school students appear to need time for thinking, a time to pause, assimilate and process information in their own developmental time. Practice on appropriate tasks will enhance student learning and assist transition into formal operational thinking.

Implications

The implications of this study should be of primary importance to educational administrators, curriculum developers, and textbook publishers, as well as teachers who have been given the charge of addressing the curricular needs of middle school students. The awareness and knowledge provided to this cadre of

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[128] Jean Piaget, as quoted in, Marcia C. Linn, Cathy Clement, and Steven Pulos, "Is It Formal if Its Not Physics? (The Influences of Content on Formal Reasoning), Journal of Research in Science Teaching 20 (Nov. 1983): 755-770.

[129] D. A. Farber and N. V. Dubrovins Kaya, "Organization of Developing Brain Functions (Age-Related Differences and Some General Principles," Human Physiology 17, no.5 (Sept./Oct. 1991): 326-335.

educators about the cognitive developmental levels of middle school adolescents should promote more holistic educational practices.

Most educators in middle schools will encounter students demonstrating reasoning patterns that have both concrete and formal elements. Many typical adolescents display erratic reasoning and behavior patterns. The adolescent body and mind are in similar disequilibrium: the body is no longer a child's and yet not really an adult's; the mind no longer thinks like a child, yet it cannot yet think like an adult. The adolescent body and mind are in transition.

In the educational setting, many times these obvious states of transition are not readily apparent to many teachers. Some educators seem to be insensitive to the students' individual differences. Teachers' expectations are frequently similar for all students. Students may be criticized for their lack of comprehension or their inability to perform certain reasoning tasks. Many lessons are presented in only one learning/teaching modality; it is usually the learning style of the teacher. Experience-based lessons using multi-modality approaches (auditory, visual, verbal, or kinesthetic) will offer a greater opportunity for more students to be successful.

Many educators defend their curriculum and teaching strategies as empirical and expect their students to modify their learning styles and behaviors when, in reality, teachers need to modify their instructional strategies. Teacher egos are so involved in their curriculum they fail to see that not all students may be interested in their subject matter. Teachers may need to create enthusiasm for their curricular area.

Typical investigations concerned with cognitive change during adolescence and puberty focus on the individual attaining a new level of adaptation toward higher logic in problem solving. The majority of curriculum areas in the middle grades review basic concepts taught in the primary grades. Educators should take this opportunity to help students refine these basic concepts. Many adolescents, who were perhaps model students in elementary school, may avoid thinking critically during the middle school years because of physical changes and social and emotional pressures. Teachers can provide the tasks that will encourage formal operational thinking.

Research has shown that while many educators expect adolescents to reason on the formal level many cannot do so.[130] Accordingly, this problem of teaching to unrealistic reasoning stages in the middle grades is prevalent throughout the educational system.[131] Reconciling the curriculum in the middle school to the students' cognitive level should produce greater student achievement

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[130] Barbara Decker and Frederick L. Silverman, "Bridging the Gap From Concrete to Full Operational Thinking in the Content Areas," Presented at the annual meeting of the World Congress on Reading of the International Reading Association (London, England, 1985), EDRS Document Reproduction Service ED 275993; William Gary and Mary Lou Rush, "Formal Operations and Social Relativistic Thinking," Presented at the Sixteenth Annual Symposium of the Jean Piaget Society, Philadelphia, 1986 (Center for Applied Cognitive Science, The University of Toledo, Toledo, Ohio), EDRS Document Reproduction Service 270235.

[131] Joyce L. Epstein, "What Matters in the Middle Grades -- Grade Span or Practices?" <u>Phi Delta Kappan</u> 71, no.6 (1990): 438-44.

and school success and diminish the amount of students who fail during the middle grades.

Recommendations

Recommendations for the Profession

The recommendations presented in this study are based on data gathered from the literature review, the empirical study which was the focus of this present research, and from experienced individuals working in middle school education.

It was not until the middle of the twentieth century that the idea of an educational level between elementary and high school came into being; junior high was the third level that evolved. By the 1960s the junior high concept came under attack because its content and methods were more appropriate for high school students. The adolescent was not being addressed, namely, their intellectual development and emotional, social, and physiological needs.[132] Transition from the protected environment of the elementary school to the more impersonal and departmentally structured junior high school was not being provided.

General dissatisfaction with the existing junior high school program led to a national middle school movement. The National Middle School Association's primary focus is a response to an educational experience specifically designed for

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[132] Jo Sue Whisler, "Young Adolescents and Middle Education: A Review of Current Issues, Concerns, and Recommendations," Mid-Continent Regional Educational Laboratory, sponsored by: Office of Educational Research and Improvement (ED), Washington, DC (Aurora, Colorado, 1990), ERIC Document Reproduction Service ED 346960.

young adolescents that responds to the full range of intellectual and developmental needs of students in transition.[133]

The association outlines essential components of a model middle school climate but does not define specifics about grades and course offerings. Improving early adolescent education has been the number one aim of middle school educators. The National Middle School Association accuses many middle school settings of creating problems because of the mismatch between the organization and the curriculum and the intellectual and emotional needs of adolescents. Remedy lies in the design and conduct of activities for students and families that ease the transition to new schools.[134]

General recommendations for overall positive trends include: interdisciplinary teams of teachers with common planning time for teachers; flexible scheduling and students assigned to the same homeroom teacher throughout the middle school years; instructional and curriculum approaches including cooperative learning and exploratory and minicourses; and encouraging

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[133] Jo Sue Whisler, "Young Adolescents and Middle Education: A Review of Current Issues, Concerns, and Recommendations," Mid-Continent Regional Educational Laboratory, sponsored by: Office of Educational Research and Improvement (ED), Washington, DC (Aurora, Colorado, 1990), ERIC Document Reproduction Service ED 346960.

[134] Ibid.

parent involvement, including parents as volunteers, and providing workshops for parents on early adolescents.[135]

Programs that value the potential of young people rather than their economic value to the nation need to be strengthened. Young people need respect, fairness, confidence in their growing integrity, and a sense of hope for themselves. When they are valued, young adolescents can be engaged and motivated to set goals for themselves.

Special programs help keep students in school and spur them into academic achievement. Special community service programs, including working with the needy, mentally less competent, or emotionally disturbed, can provide valuable resources for the community. Leadership programs can provide opportunities for students not considered leaders. Service programs such as recycling projects can bring about awareness and environmental change. It is recommended that these programs become part of the traditional school structure rather than alternative programs.[136]

In the curricular areas, it is recommended, based on research, that activities requiring complex skills be kept to a minimum to avoid student "turn-off." Educators should provide tasks to evaluate the cognitive abilities of their students.

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[135] Joyce L. Epstein, "What Matters in the Middle Grades -- Grade Span or Practices?" Phi Delta Kappan 71, no.6 (1990): 438-44.

[136] Anne C. Lewis, "On Valuing Young People," Phi Delta Kappan 71 (Feb. 1990): 420-21.

Teachers must modify their curriculum and instructional strategies to meet the cognitive development needs of their students. Educators should provide appropriate tasks to foster the development of formal operational thinking. More information about cognitive development stages needs to be available to all educators. In-services for staff should be provided to help teachers align instructional strategies with middle school students' abilities.

Recommendations in the area of assessment include using high interest materials with familiar content that encourages presolution thinking. Traditional assessment procedures should be questioned when used with students from multi-cultural bilingual families or families with little schooling. As part of the instructional program, teachers should design assessments and keep portolios that evaluate students' cognitive capabilities.

Concluding recommendations are concerned with the holistic approach to education and how the school, teacher, and student interaction is perceived. The ability to make plans and carry them out is the key aspect of intelligence. Yet teachers commonly do the planning as dictated by administrators or curriculum frameworks. Students need the opportunity to plan their learning experiences with teachers acting as facilitators.

Many important discoveries did not happen in logical ways. Many researchers stumble onto solutions after several unsuccessful logical attempts.[137]

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[137] Morton Hunt, The Universe Within (New York: Simon & Schuster, 1982), 121.

It has only been in recent years that education has attempted to design brain compatible instruction. The "Decade of the Brain" helped to launch instruction more pro-active with the brain. Only a fragmentary amount of useful knowledge has been produced on how humans have learned over the centuries of teaching.[138]

Recommendations for Further Research

Recommendations for future research on middle school students' cognitive ability must continue to maintain a growing focus on providing appropriate middle school education. Brain research should continue to provide more information on brain development growth spurts during the adolescent years. More investigations are needed on the relationship between the valley in brain growth during adolescence and the final development of the frontal lobes. Future research should continue to investigate how middle school students think and the type of activities that produce success. Action research must be conducted to provide more knowledge of appropriate lesson designs and strategies for adolescents. Future research on the relationship between students enrolled in algebra in middle school and their performance on tests of proportionality would give more conclusive information about the value of teaching algebra to adolescents. General research into the way adolescents think, perceive themselves, and how important they view school in their lives must continue.

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[138] Leslie A. Hart, Human Brain and Human Learning, (New York, New York: Longman, 1983).

To understand the Puzzle of Genius and where great minds come from is to realize that genius is not about being smart. It is not about getting As in school or scoring high on achievement and aptitude tests; it is more about having an elusive and divergent way of thinking and viewing the world. Geniuses do not merely solve problems; they identify new ones. Einstein, Freud, Martha Graham, Picasso, and T.S. Eliot all transcended the solutions of problems already posed. Geniuses form more novel combinations than people who are merely talented. Great minds entertain permutations of images and memories that conventional thinkers toss away. Creative geniuses are willing to take intellectual risk by combining disparate ideas. Geniuses have a tolerance for ambiguity, a patience with unpredictable events or thoughts. They delight in having no particular intellectual destination or schedule. Intellectual rambling allows the genius to connect what others have never considered.[139]

Education must consider exemplary programs that encourage policy makers about restructuring schools, dodge regulations in pursuit of accomplishing what is important in school and have a different view of the use of time in school.

> The brain existed long before the classroom, and so can hardly be dependent on what happens in a few hours of school to become educated.[140]

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[139] Sharon Begley, "Where Do Great Minds Come From? And Why are There No Einsteins, Freuds, or Picassos Today?," Newsweek (June 28, 1993): 46.

[140] Leslie A. Hart, Human Brain and Human Learning (New York, New York: Longman Inc. 1983), 43.

APPENDICES

APPENDIX A

Proclamation 6158 of July 17, 1990

Decade of the Brain, 1990-1999

55 F.R. 29553

By the President of the United States

A Proclamation

The human brain, a 3-pound mass of interwoven nerve cells that controls our activity, is one of the most magnificent--and mysterious--wonders of creation. The seat of human intelligence, interpreter of senses, and controller of movement, this incredible organ continues to intrigue scientist and layman alike.

Over the years, our understanding of the brain--how it works, what goes wrong when it is injured or diseased--has increased dramatically. However, we still have much more to learn. The need for continued study of the brain is compelling: millions of Americans are affected each year by disorders of the brain ranging from neurogenetic diseases to degenerative disorders such as Alzheimer's, as well as stroke, schizophrenia, autism, and impairments of speech, language, and hearing.

Today, these individuals and their families are justifiably hopeful, for a new era of discovery is dawning in brain research. Powerful microscopes, major strides in the study of genetics, and advanced brain imaging devices are giving physicians and scientists ever greater insight into the brain. Neuroscientists are mapping the brain's biochemical circuitry, which may help produce more effective drugs for alleviating the suffering of those who have Alzheimer's or Parkinson's disease. By studying how the brain's cells and chemicals develop, interact, and communicate with the rest of the body, investigators are also developing improved treatments for people incapacitated by spinal cord injuries, depressive disorders, and epileptic seizures. Breakthroughs in molecular genetics show great promise of yielding methods to treat and prevent Huntington's disease, the muscular dystrophies, and other life-threatening disorders.

Research may also prove valuable in our war on drugs, as studies provide great insight into how people become addicted to drugs and how drugs affect the brain. These studies may also help produce effective treatments for chemical dependency and help us to understand and prevent the harm done to the preborn children of pregnant women who abuse drugs and alcohol. Because there is a connection between the body's nervous and immune systems, studies of the brain may also help enhance our understanding of Acquired Immune Deficiency Syndrome.

Many studies regarding the human brain have been planned and conducted by scientists at the National Institutes of Health, the National Institute of Mental Health, and other Federal research agencies. Augmenting Federal efforts are programs supported by private foundations and industry. The cooperation between these agencies and the multidisciplinary efforts of thousands of scientists and health care professionals provide powerful evidence of our Nation's determination to conquer brain disease.

To enhance public awareness of the benefits to be derived from brain research, the Congress, by House Joint Resolution 174, has designated the decade beginning January 1, 1990, as the "Decade of the Brain" and has authorized and requested the President to issue a proclamation in observance of this occasion.

NOW, THEREFORE, I, GEORGE BUSH, President of the United States of America, do hereby proclaim the decade beginning January 1, 1990, as the Decade of the Brain. I call upon all public officials and the people of the United States to observe that decade with appropriate programs, ceremonies, and activities.

IN WITNESS WHEREOF, I have hereunto set my hand this seventeenth day of July, in the year of our Lord nineteen hundred and ninety, and of the Independence of the United States of America the two hundred and fifteenth.

/s/ George Bush[140]

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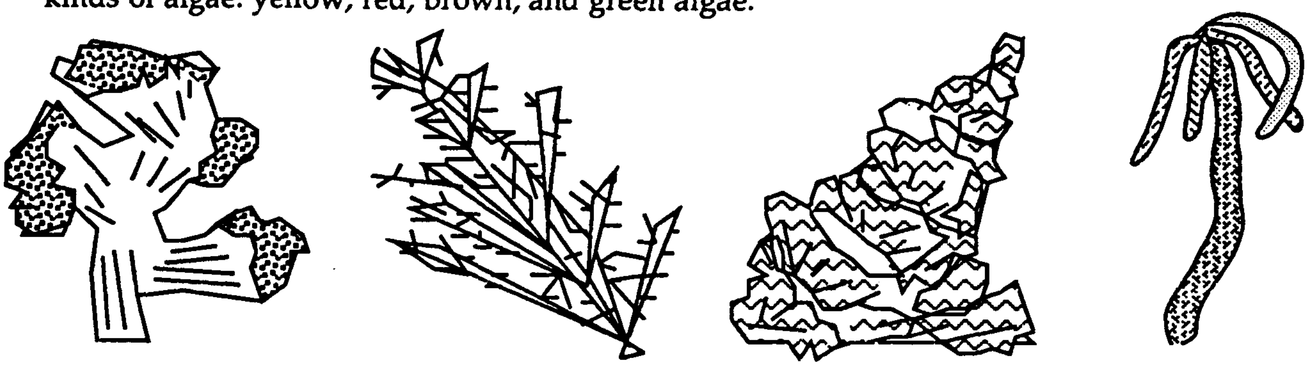
[140] President, Proclamation, "Decade of the Brain, 1990-1999, Proclamation 6158," Federal Register (July 17, 1990), 55, 29553.

APPENDIX B

Name ______________________ Grade __________
Sex ______________________ Age __________
Ethnicity ______________________ Date of Birth __________

THE ALGAE PUZZLE

A population of crabs which eats algae lives on a seashore. On the seashore there are four kinds of algae: yellow, red, brown, and green algae.



Yellow--Y   Red--R   Green--G   Brown--B

Dr. Saltspray, a biologist, is interested in determining which of the types of algae are actually eaten by the crabs. He plans to find out by examining the stomach contents of the crabs. Before he does his investigation he lists all the combinations of algae he thinks possible to find in the stomachs. Write down each possible combination of algae he can find. Use letters Y, R, G, and B to save space.

____

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____

____

Looking back, how did you think your way through the problem: Did you think at once of the ways to do it, or did you first think of a way that had to be modified or abandoned?

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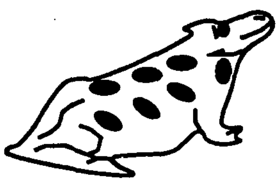
APPENDIX C

Name ______________________________ Grade ____________
Sex ______________________________ Age ____________
Ethnicity ______________________________ Date of Birth ____________

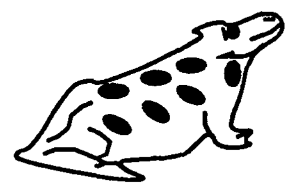
THE FROG PUZZLE

Professor Thistlebush, an ecologist, conducted an experiment to determine the number of frogs that live in a pond near the field station. Since he could not catch all of the frogs, he caught as many as he could, put a white band around their left hind legs and then put them back in the pond. A week later he returned to the pond and again caught as many frogs as he could. Here is the professor's data.



First trip to the pond
55 frogs caught and banded

Second trip to the pond
72 frogs caught, of those 72 frogs
12 were banded



Total number of frogs in the pond

____

The Professor assumed that the banded frogs had mixed thoroughly with the unbanded frogs, and from his data he was able to approximate the number of frogs that live in the pond. If you can compute this number, please do so. Write it in the blank above, and in the space below explain in words how you calculated your result.

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____
____
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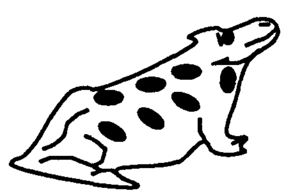
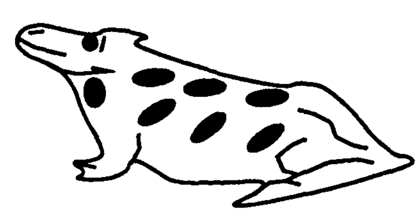


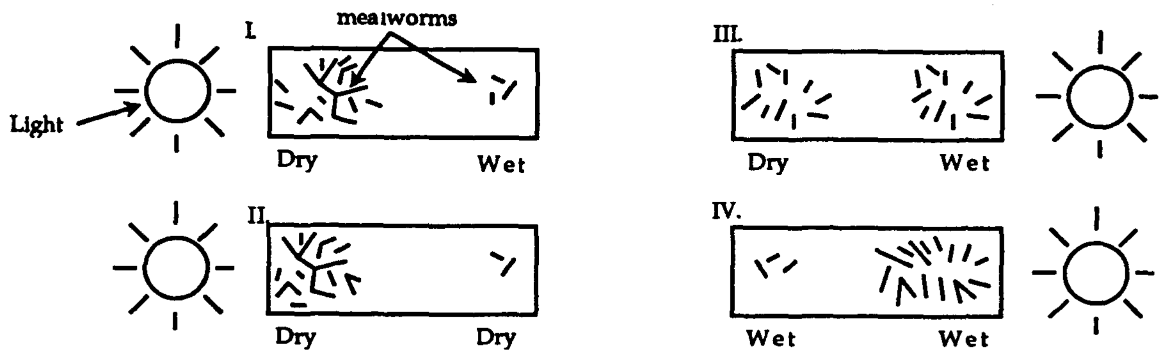


APPENDIX D

Name ______________________ Grade ______
Sex ______________________ Age ______
Ethnicity ______________________ Date of Birth ______

THE MEALWORM PUZZLE

An experimenter wanted to test the response of mealworms to light and moisture. To do this he set up four boxes as shown in the diagram below. He used lamps for light sources and constantly watered pieces of paper in the boxes for moisture. In the center of each box he placed 20 mealworms. One day later he returned to count the number of mealworms that had crawled to the different ends of the boxes.



The diagrams show that mealworms respond to (response means move toward or away from):

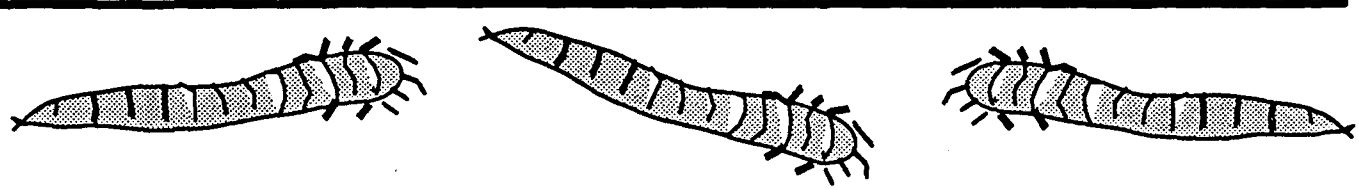
(A) light but not moisture.

(B) moisture but not light.

(C) both light and moisture.

(D) neither light nor moisture.

Please explain your choice ______________________



APPENDIX E

The following pages contain samples of metacognitive statements for each cognitive developmental level--Preoperational, Concrete, Formal I, and Formal II. The statements are representative of each grade (6, 7, and 8) within the socio-economic status levels (high, middle, and low) from the three middle schools involved in the study.

High SES -- Grade 6

Algae	Frog	Mealworm
#1 Preoperational		
"I just wrote down letter." "All I did was take numbers and scramble them around." "I thought at once how to do it." "I started by putting all the numbers I could think of and then I put them in order."	"To get my result I just added the total amount of frogs that were banded and unbanded."	"Well, I looked at how many like light (a lot). Then I looked at how many like wet (good amount). Then I looked at how many like dry (most). So I picked light but no moisture."
#2 Concrete		
"I did kind of both. At first I picked any combination and then I did it organized." "I first did Y. There were 3 ways. Then I did R. There were 2 ways. Then I did G. There was only one way."	None available	None available
#3 Formal I		
"I thought it might be good to list each color with each color, except itself and then I could find out how many combinations were found. And then I saw that there were more ways and maybe 4 or 3 different types."	None available	None available
#4 Formal II		
"The way I thought about it was how there could be a sequence to find all of them. I kind of rushed through this because there are so many ways but I did think of ways to do it."	None available	"The mealworms on the diagram show that they went wherever side the light was at, whether it was wet or dry."

High SES -- Grade 7

Algae	Frog	Mealworm
#1 Preoperational		
"I think he will eat Y and B in one time because Y and B look better, and R-G He will eat together because they look better." "Because it looks like more algae is on it and it looks like it would be more healthier."	"I first subtracted 12 from 72, which was 60. Then I added 55- to 60 which was 115."	None available
#2 Concrete		
"I thought at once of the ways to do it." "I just listed combos."	None available	"In all the boxes some went toward the light, but not all. And in Box I and Box II some stayed in dry areas when some others went to wet."
#3 Formal I		
"To do this program you just had to come up with a pattern. I thought of it right away."	None available	"I chose C, because in Figure III the wet and dry section there was the same amount of worms but I also think it varied on where the sun was coming from."
#4 Formal II		
None available	"There were 55 that he caught the first day and band so if they mixed throughly the next day only 1/6 were already banded. So 55= 1/6 of N 6x55=N N=330."	"Both light and moisture because in all the pictures, most of the worms crawled to the side of the box with the light source no matter if it was wet or dry."

High SES -- Grade 8

Algae	Frog	Mealworm
#1 Preoperational		
"I thought at once of the ways to do it."	"Well, since the second trip 12 were already banded I subtracted 12 from 72 and got 60. I then added 60 and 55 to get the answer 115."	"At first the mealworms are in the dryer place of the box and as the days pass most of them go to the wet area. Light has nothing to do with it."
#2 Concrete		
"I tried to think of a plan of orders to write them."	"I multiplied 72x6 because if they (the original banded frogs) were all distributed in the pond evenly then 12x72 could tell you all the frogs." [Her answer was 432.]	"It looks like most of the mealworms chose to go towards the light. But you could not determine that until you did more examples. There are many variables that should be looked at in the next experiment."
#3 Formal I		
"It took me two times to do this. It is maybe not complete enough as it should be but it is the best I can do."	None available	"...because at first none of them liked the water yet after a couple days with dryness and a light source they preferred the water."
#4 Formal II		
"I knew there would be alot of combinations so I started with Y and did all of those combinations then R, G, B. I made sure I didn't do anything twice."	None available	"I think that they respond to light and moisture because in some of the boxes there are alot of worms in the dry places. But in Box III the worms are divided up equally into the dry and wet places."

Middle SES -- Grade 6

Algae	Frog	Mealworm
#1 Preoperational		
"The way I solved this problem by thinking about it." "I looked at all the possible combinations and then wrote them all down." "I wrote all of them down at once."	"I looked at the first problem and it said 55 frogs were caught but all of them were banded. In the second problem it said that 72 were caught but only 12 were banded so I subtracted 12 from 72 and I got the answer." "I added up 55 and 72 and got 127 then I added 12 with that and got 139 frogs."	"I chose A because the worms were mostly going to the light then any other choice."
#2 Concrete		
"I thought if I did Y-R, then Y-G, the Y-B I could get all of them. Then I did all the combinations for each color." "I knew I had to start with one and add to it. I was right the first time."	None available	None available
#3 Formal I		
"All I did was take each different algae and kept mixing them up until there were no more." "I thought about putting every single color in 6 combinations and it worked." "I placed the letters in different ways so I had to have more space then I thought that R was the very spikey one so I decided that it won't be able to go in the crabs stomach. (It wasn't that hard.)"	None available	None available

Middle SES -- Grade 6 (continued)

Algae	Frog	Mealworm
#4 Formal II		
"I just put as many together as possible, then I first put a main algae the mixed the other algae to make a different combo." "When I heard the word combination I just did as much as I could."	None available	"Number III has half of them in the moisture and dry. So picked number III." "I picked C because some days the mealworms like dry sometime wet. You never see dry or a wet space that doesn't have a worm in it."

Middle SES -- Grade 7

Algae	Frog	Mealworm
#1 Preoperational		
"I saw that there had to be different letters in everyone and worked on that." "I thought of one at a time." "I have already done a problem using this method above, so I knew right away what to do, so I just did it." "I did it in a systematic way. I thought at once of a way to do it. I started with a letter and another and then switched the last two, all the way through, until I got 24."	"I looked at the number of frogs on the page." "I added the number of frogs he caught both days, but I'm wondering that he could have missed a lot of the frogs without even knowing it or some frogs might have gotten out of the banding without him even knowing." "The Professor caught 55 frogs and 127 frogs which equals 127 frogs. This may not be totally correct because the Professor did not catch all the frogs." "I don't get it."	"Because I don't like this very much."
#2 Concrete		
"I took two things down if they would not go I would erase it. I don't get it!" "I thought of the ways as I went." "I thought at once what to do. I just kept matching. Like first I took Y and went through the letters. Then I took R and saw the letters that didn't match yet and etc."	"The facts are that 55 frogs had bands. When the 72 frogs were caught the next day, only 12 had bands. By subtracting 12 from 72, you find that 60 of them were not banded. If 55 are banded and 60 are not, that is a total of 115. But, there may be more frogs that haven't been caught yet, so that's why I say <u>at least</u> 115."	"I picked A because in all of the boxes but one the mealworms liked light but not moisture." "I chose A because the mealworms went into the light and in the end there were 16 in the wet and 4 in the wet. Kinda confusing."

Algae	Frog	Mealworm
#3 Formal I		
"...All I did was use a pattern. There aren't all the ways to do their problem. I left out a few of the possible ways to do them." "I've done similar problems, so I just started listing."	None available	None available
#4 Formal II		
None available	None available	"Well, the mealworms would be dry and the light would heat them up so they would go on to the wet side, then get wet and go on to the dry side, and so on for 4 days." "Because they all didn't go to one side or the other they responded more to dry but some went to moisture. So they responded to both."

Middle SES -- Grade 8

Algae	Frog	Mealworm
#1 Preoperational		
"I started with one letter then I went through all the possible combinations." "I thought at once of a way that had to be modified and abandoned and I'm thinking hard because B, R (Brown and Red) are dead colors."	"Because of all the 72 he caught the 55 of them weren't banded because they already were. Then 12 more were banded making 67 but 5 of the 72 weren't banded making a total of 72." "Well, I took 55 banded frogs and took 12 away from that. That left me with 43. So, 43+72=115."	None available
#2 Concrete		
"The way to do it, I thought that their would be nine different ways to have algae in a crab stomach." "I picked a letter Y, and listed all the different possibilities."	"Added them together and added some more."	"Well, more mealworms went for the light but they do not like wet side but some still do." "They always are on a majority by the light."
#3 Formal I		
"I was wondering how, because I think they need a little more info on the question. I was wondering what these people were talking about." "First I thought what is the question asking then I thought of ways to answer it and the different possible answers it could want."	None available	None available

Middle SES -- Grade 8 (continued)

Algae	Frog	Mealworm
#4 Formal II		
"I just used a pattern. I don't like this problem."	"First, I thought of different ways I could possibly do this then I divided 55 by 12 - took that number 4.5833 and multiplied it by 72 to get an estimated answer of about how many frogs are in the pond." "I divided 12 into 72 and got 6 and then times that with 55 and got 330."	"Most of the worms are where there is both light and moisture." "They, in Day 3, didn't all go to the wet side because they like dry. They probably wouldn't mind being wet if the sun was in the "wet zone".

Low SES -- Grade 6

Algae	Frog	Mealworm
#1 Preoperational		
"Well many crabs are red and some they are red and brown and Y and B you know how crabs are red when they are alive." "The crab can eat the algae two at a time. He can mash them and he can get it all dirty. He can eat little pieces. He can swallow it whole." "I thought how to do it quickly and I was just thinking of stuff off the top of my head." "Y, R, G, B, on Y the crab could start from the bottom until it falls. On R the crab could cut one by one down and eat. On G start from the top down. On B just eat until it falls." "First I would put G in my mouth because it looks like its hard, then I'd put R because it is spiky then I'd put Y because it looks smooth and last one I'd put in my mouth is B because it looks smooshy and soft. First I thought of a way that had to be modified or abanded." "Y, R, G, and B. They swallow it whole. I had to read it alot." "The algae that the crabs would like most are the R algaes. The R algaes must taste good and the crabs eat them all the time. That's why the crabs are red. They might	"What I did was I looked at the data. I read 55 frogs caught and banded so I know 55 frogs were banded and I also saw 12 banded so what I did was I added both up and my answer 67 were left." [He drew bands around the frogs legs.]	"I couldn't do this one - because they didn't give me enough information."

Low SES -- Grade 6 (continued)

Algae	Frog	Mealworm
#1 Preoperational (continued)		
like the R algaes cause it's thick and spiky. How I did the problem was I had to think awhile and asked for some help. Then I thought about how crabs are red so red algaes must turn them red cause they ate too much R algaes." "I think he will find G algae because crabs like on a sea or in the ocean and on the rocks it is just green algae. I have never seen any other color." "I think I did well because algae is only green. Well at least thats the only color I've seen it be. The way I did it is I just thought of what color is algae." "I said I would B and Y together and R and G separate."		
#2 Concrete		
"I knew how to do it right away. I got how to do it that is why."	None available	"'D' because in diagram II all of the mealworms are dry but they are at different ends. Also diagram IV shows that they are all wet so there must be different watts in the bulb."

Low SES -- Grade 6 (continued)

Algae	Frog	Mealworm
#3 Formal I		
"I just put together different combinations and if I've already used one then I'd leave it out."	None available	"I think that they like both light and moisture because you can see that they like it. Because they are mostly in wet. They will go to the light in the dry."
#4 Formal II		
None available	None available	"They were on both ends but most of them were on the dry side, but in a way it looked like a tie." "I chose number C because the worms moved when he put the light and water there."

Low SES - Grade 7

Algae	Frog	Mealworm
#1 Preoperational		
"I thought of each color Y, R, G, B." "I looked for a way to modify a strategy to obtain at least half of the ways possible." "To solve this problem I counted by hand and there are 24 combinations." "I made up an idea."	"The way I calculated this result was that I just added or they could be any answer." "I think to total of the frogs that were in the pond were 139 because if you add 55 and 72 and 12 = 139 so that would be all the frogs together in the pond."	"A - Because there is more on that side."
#2 Concrete		
"I thought it through and my strategy is going one by one." "I did this kind of work in 3rd grade, so I had no second thought to my first guess."	None available	"The mealworms like light because it is hot but the moisture is damp and wet so it is not like the mealworms to go to the moisture." "The mealworms don't like light nor moisture."
#3 Formal I		
"I thought my way through the problem was by thinking the ways they can be changed. I just change everyone around and move them."	None available	None available

Low SES -- Grade 7 (continued)

Algae	Frog	Mealworm
#4 Formal II		
None available	None available	"Because he returned to count the number of mealworms that had crawled to the different ends of the boxes. So that tells us that mealworms do have a response to light and moisture." "I picked C. I think they like both light and moisture because some worms stayed in the light some worms went to wet side so they like both."

Low SES -- Grade 8

Algae	Frog	Mealworm
#1 Preoperational		
"I just looked at the size of the algae." "I first did all the ones starting with one letter then multiplied the # by how many letters their are." "I like green the best." "I thought my way to the problem by trying as hard as I can to figure out to problem." "I already knew the answer was going to be 16 because if you have like 4 you times it again and get your answer."	"55 from the first rip and 12 frogs from the second so that is 62 frogs." "I just added 72 and 55 to get my answer." "I added 55 and 72, then took away 12."	None available
#2 Concrete		
"I started with the first algae and made sure it went with all of the others, then went onto the second algae and put it with the behind algaes, etc." "I did these problems immediately they were easy so I did think of the ways at once how to do it."	None available	"I thought that the worms liked light but not moisture, because on #1 and 2 they seemed to like the light and dry better and there were clearly more than #III and #4." "From the patterns I see it looks like there are no patterns so I believe it is random."
#3 Formal I		
"At first I couldn't understand what the question was asking but when I saw what it meant it was easy. I finished fast." "I just got it."	None available	None available

Low SES -- Grade 8 (continued)

Algae	Frog	Mealworm
#4 Formal II		
"The way I thought of solving the problem was just finding ways to combine the different kinds of algae. I combined them using either with one, two, three, or four algae names." "I did it by making a small graph putting all the combinations I know w/out repeating."	None available	"I chose letter C because as I look on the chart I see that the mealworms respond to wherever the *light is.*" "I think the worms liked moisture with light because it warms them."

BIBLIOGRAPHY

Ackerman, Sandra, "Discovering the Brain," To the Institute of Medicine National Academy of Sciences (Washington, D.C.: National Academy Press, 1992).

Barratt, Barnaby B., "Training and Transfer in Combinatorial Problem Solving: The Development of Formal Reasoning During Early Adolescence," Developmental Psychology 11 (1975): 700-704.

Berk, Laura E., "Why Children Talk to Themselves," Scientific American 271 (1994): 78-83.

Bybee, Roger W. and Robert B. Sund, Piaget for Educators (Columbus, Ohio: Charles E. Merrill Publishing Company, 1982).

Carey, Joseph (ed. and Public Information Director, Society for Neuroscience), Brain Facts A Primer on the Brain and Nervous System (Woodland, MD: Graphtec Inc., 1993).

Carnegie Council on Adolescent Development, Turning Points (New York, New York: Carnegie Corporation of New York, 1989).

Case, Robbie, "The Role of the Frontal Lobes in Regulation of Cognitive Development," Brain and Cognition 20 (1992): 51-73.

Case, Robert, "Structures and Strictures, Some Functional Limitations on the Course of Cognitive Growth," Cognitive Psychology, 16 (1974): 544-573.

Day, Mary Carol, "Thinking at Piaget's Stage of Formal Operations," Educational Leadership (October 1981): 44-47.

Decker, Barbara C. and Fredrick L. Silverman, "Bridging the Gap From Concrete to Full Operational Thinking in the Content Areas," Presented at the annual meeting of the World Congress on Reading of the International Reading Association (London, England, 1985), EDRS Document Reproduction Service ED 275993.

Diamond, Marian C., Enriching Heredity The Impact of the Environment on the Anatomy of the Brain (New York: The Free Press, 1988).

Edelman, Gerald, Bright Air, Brilliant Fire: On the Matter of the Mind (New York: Basic Books, 1992).

Education USA 27 (1985): 347.

Elkind, David, "Egocentrism in Adolescence," Child Development 38 (1969): 1025-1034.

Epstein, Herman, "Phrenoblysis: Special Brain and Growth Periods I - Human Brain and Skull Development," Developmental Psycho-biology, 7 (1974): 207-216.

Epstein, Herman and Connie Toepfer, "A Neuroscience Basis for Reorganizing Middle Grades Education," Educational Leadership 36 (1978): 656-660.

Epstein, Joyce L., "What Matters in the Middle Grades -- Grade Span or Practices?" Phi Delta Kappar 71, no.6 (1990): 438-44.

Farber, D. A. and N. V. Dubrovins Kaya, "Organization of Developing Brain Functions (Age-Related Differences and Some General Principles)," Human Physiology 17, no.5 (Sept./Oct. 1991): 326-335.

Friedman, Stephan and George Kilodiy, "A Model Program for Development of Verbal and Quantitative Reasoning Skills," Problem Solving 5 (1983): 1-5.

Gardner, Howard, Frames of Mind: The Theory of Multiple Intelligences (New York: Basic Books, 1983).

Gary, William and Mary Lou Rush, "Formal Operations and Social Relativistic Thinking," Presented at the Sixteenth Annual Symposium of the Jean Piaget Society, Philadelphia, 1986 (Center for Applied Cognitive Science, The University of Toledo, Toledo, Ohio), EDRS Document Reproduction Service 270235.

Gazzaniga, Michael, Natures Mind: The Biological Roots of Thinking, Emotions, Sexuality, Language and Intelligence (New York: Basic Books, 1992).

Hart, Leslie A., Human Brain and Human Learning (New York, New York: Longman Inc. 1983).

Honig, Bill, Caught in the Middle Educational Reform for Young Adolescents in California Public Schools (California State Department of Education, Sacramento, California: 1987): 65.

Hunt, Morton, The Universe Within (New York: Simon & Schuster, 1982), 121.

Inhelder, Barbel and Jean Piaget, The Growth of Logical Thinking: From Childhood to Adolescence (New York: Basic Books, 1958).

Krajcik, Joseph and Richard E. Haney, "Proportional Reasoning and Achievement in High School Chemistry," School Science and Mathematics 87 (1987): 25-35.

Lawson, Anton E., Ph.D., Science Curriculum Improvement Study (University of California, Berkeley, California, 1965-1975), Grant No. SED74-18950.

Lawson, Anton E. and John Renner, "Piagetian Theory and Biology Teaching," American Biology Teacher 37 (1975): 336-343.

Lawson, Anton E. and Gene D. Shepherd, "Written Language Maturity and Formal Reasoning in Male and Female Adolescents," Language and Speech 22 (1978): 117-127.

Linn, Marcia C., "Theoretical and Practical Significance of Formal Reasoning," Journal of Research in Science Teaching 19, no.9 (December 1982): 727-42.

Linn, Marcia C., Cathy Clement, and Steven Pulos, "Is It Formal if Its Not Physics? (The Influences of Content on Formal Reasoning), Journal of Research in Science Teaching 20 (Nov. 1983): 755-770.

Lowery, Lawrence F., Thinking and Learning Matching Developmental Stages With Curriculum and Instruction (Pacific Grove, California: Midwest Publications, 1989).

Maker, C. June, "Identification of Gifted Minority Students: A National Problem and an Emerging Paradigm," Manuscript submitted for publication, 1994.

Maker, C. June, Aleene B. Nielson, Judith A. Rogers, "Giftedness, Diversity, and Problem-Solving," The Council for Exceptional Children, Teaching Exceptional Children, 27, no.1 (Fall 1994): 4-18.

Marini, Zopito and Robbie Case, "The Development of Abstract Reasoning About the Physical and Social World," Child Development 65 (Feb. 1994), 147-59.

Martinez, Joseph G. and Nancy C. Martinez, "Are Basic Writers Cognitively Different?" Paper presented at the WCRLA Conference, 1987, EDRS Document Reproduction Service ED 285179.

Mattheis, Floyd E., William E. Spooner, Charles R. Coble, Shigekazu Takemura and Shinji Matsumoto, Katsunobu Matsumoto, Atsushi Yoshida, "A Study of the Logical Thinking Skills and Integrated Process Skills of Junior High Students in North Carolina and Japan," Science Education 76, no. 2 (1992): 211-222.

Mayer, Richard E., "Cognition and Instruction: Their Historic Meeting Within Educational Psychology," Journal of Educational Psychology 84 (1992): 405-412.

McEwin, C. Kenneth and Julia T. Thomason, Who They Are-How We Teach: Early Adolescents and Their Teachers (Columbus, Ohio: National Middle School Association, 1989).

Neimark, Edith D., "A Preliminary Search for Formal Operations Structures," The Journal of Genetic Psychology 116 (1970): 223-232.

Pace, Sandra Falconer, "Students' Thinking: Developmental Framework Cognitive Domain," (Report No. SBN-0-920794-60-2, Alberta Department of Education, Alberta, Canada, 1987), EDRS Document Reproduction Service ED 287570.

Pellegrini, Anthony D., "Some Questions about the Basic Tenets of Brain Periodization Research," Journal of Instructional Psychology 11, no. 3 (1984): 165-169

Piaget, Jean, "Intellectual Evolution from Adolescence to Adulthood," Human Development 15 (1972): 1-12.

________. Psychology of Intelligence (Totowa, New Jersey: Littlefield, Adams and Company, 1969).

President, Proclamation, "Decade of the Brain, 1990-1999, Proclamation 6158," Federal Register (July 17, 1990), 55, 29553.

Quay, Lorene C., "Interactions of Stimulus Materials, Age, and SES in the Assessment of Cognitive Abilities," Journal of Applied Developmental Psychology 10, no.3 (July-Sept 1989): 401-409.

Restak, Richard M., M.D., The Infant Mind (Garden City, New York: Double Day & Company, 1986).

________. The Mind (New York, New York: Bantam Books, 1988).

Roberge, James J. and Barbara K. Flexer, "Further Examination of Formal Operational Reasoning Abilities," Child Development 50 (June 1979), 478-484.

Shayer, Michael and Philip S. Adey, "Accelerating the Development of Formal Thinking in Middle and High School Students IV: Three Years After a Two-Year Intervention," Journal of Research in Science Teaching 30, no. 4 (1993): 351-366.

Stuss, Donald, "Biological and Psychological Development of Executive Functions," Brain and Cognition 20 (1992): 8-23.

Sylwester, Robert, "What the Biology of the Brain Tells Us About Learning," Educational Leadership, December 1993/January 1994.

Thatcher, Robert W., R. A. Walker, S. Guidice, "Human Cerebral Hemispheres Develop at Different Rates and Ages," Science 236 (May 1987): 1110-13.

Thornburg, Hershel D., "The Counselor's Impact on Middle Grade Students," School Counselor 33, no.3 (1986): 170-177.

Thornburg, Hershel D., K. L. Adey and E. Finnis, "A Comparison of Gifted and Nongifted Early Adolescents' Movement Toward Abstract Thinking," Paper presented at the annual meeting of the American Educational Research Association, Chicago, Illinois, March 1985.

Toepfer, Connie, "Brain Growth Periodization: Implications for Middle Grade Education," Schools in the Middle (April 1981): 1-6.

Touwen, Dr. Bert C. L., as quoted in Richard M. Restak, M.D., The Infant Mind (Garden City, NY: Double Day & Company Inc., 1986), 120.

Van Hoose, John and David Strahan, Young Adolescent Development and School Practices: Promoting Harmony (Columbus, Ohio: National Middle School Association, 1988).

Vygotsky, Lev Semenovick, "The Problem of Age-Periodization of Child Development," Human Development 17 (1974): 24-40.

_______. Mind in Society: The Development of Higher Psychological Processes, eds. M. Cole, V. John-Steiner, S. Scribner, and E. Souberman (Cambridge, MA: Harvard University Press, 1978).

________. Thinking and Speech, ed. and trans. N. Minnick (New York: Plenum, 1987) (translation of Vygotsky, 1982 b).

Wertsch, James V. and Peter Tulviste, "L.S. Vygotsky and Contemporary Developmental Psychology," Developmental Psychology 28 (1992): 548-557.

Whisler, Jo Sue, "Young Adolescents and Middle Education: A Review of Current Issues, Concerns, and Recommendations," Mid-Continent Regional Educational Laboratory, sponsored by: Office of Educational Research and Improvement (ED), Washington, DC (Aurora, Colorado, 1990), ERIC Document Reproduction Service ED 346960.

Winick, Myron, "Changes in Nucleic Acid and Protein Content of the Human Brain During Growth," Pediatric Resident 2 (1968): 352-355.