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ABSTRACT

The purpose of this study was to determine the level of reasoning of a convenience sample of all seventh through twelfth grade students (N=156) in a consolidated school district in rural Arkansas prior to the introduction of a thinking program in which logical thinking is one component. Four research questions were investigated: (1) What percentage of seventh through twelfth grade students are formal operational thinkers as measured by the Group Assessment of Logical Thinking (GALT)? (2) Are there significant differences in the level of thinking as measured on the GALT among seventh through twelfth grade students? (3) Are there gender differences in logical lthinking ability of seventh through twelfth grade students as measured by the GALT? and (4) What are the underlying differences among seventh through twelfth grade students classified as formal, transitional, or concrete operational? The 12-item abbreviated form of GALT was selected to measure the reasoning level of the sample. Eleven percent of the sample measured formal operational on the GALT. Significant results in favor of the tenth grade group were found. Significant values were found in favor of the males on the conservation mode, conservation of volume, and probabilistic reasoning and in favor of the females on combinatorial logic. (CW)

THE GALT: A MEASURE OF LOGICAL THINKING ABILITY

OF 7TH THROUGH 12TH GRADE STUDENTS

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The GALT:
A Measure of Logical Thinking Ability of 7th through 12th Grade Students

Abstract

The Group Assessment of Logical Thinking (GALT) (Roadrangka, Yeany, & Padilla, 1982) was used to determine the reasoning level of a convenience sample of seventh through twelfth grade students (N = 156) and logical thinking as a unitary construct. Eleven percent of the sample measured formal operational on the GALT. The results of the one-way ANOVA (GALT by grade) was significant in favor of the tenth grade group. Significant t-values were found in favor of the males on the conservation mode, conservation of volume (item 4), and probabilistic reasoning (item 16) and in favor of the females combinatorial logic (dance). The principal components analysis of the six reasoning modes of the GALT resulted in all items loading on factor 1 except items 1 and 4, both conservation problems, and item 13, a probabilistic reasoning problem, which loaded on factor 2. The total explained variance was 44.5%.

The GALT: A Measure of Logical Thinking Ability of 7th through 12th Grade Students

Functioning in the "Informational Age Society" necessitates processing information (Naisbitt, 1982; Toffler, 1980) rather than just memorizing facts. A challenge of the "Information Age Society" (Naisbitt, 1982) is the development of scientifically and technologically literate citizens (James & Kurtz, 1985; National Science Board Commission, 1983; Yager, 1984). Scientific and technological literacy depends on the understanding of and the application of scientific concepts, laws, and principles. Many scientific concepts, laws, and principles such as atomic structure, energy, force, and motion demand logical thought processes. Inhelder and Piaget (1958) advanced the need for the development of propositional logic, of formal operational schemata, and of the integration of these operational schemata and propositional logic as essential logical reasoning operations. The development of logical reasoning occurs between the ages of nine and fifteen (Inhelder & Piaget, 1958). It is also at these ages that science as a separate subject area is introduced in the school.

The structure of formal operational reasoning has been questioned. Formal operational reasoning as a unitary construct has been supported by Lawson (1977, 1982); Lawson and Renner (1975); Tobin and Capie (1980a, 1980b, 1981); and Roadrangka, Yeany, and Padilla (1983). Other researchers (e.g., Ahlawat & Billeh, 1982; Bitner, 1986; Karplus, Adi, & Lawson, 1980; Lawson, 1978; Lawson, Karplus, Adi, 1978; Levine & Linn, 1977; Staver & Gabel, 1979) found that formal operational reasoning is not a unitary construct. Lawson (1982b) concluded that a unitary structure of formal operational thinking will be found if the instrument of logical thinking measures only four problems (i.e., proportional reasoning, control of variables, correlational reasoning, and probabilistic reasoning). In addition, he identified three other criteria for establishing formal operational thinking as a unitary structure: (a) homogeneity of the sample in respect to age, (b) heterogeneity of the sample in respect to mental ability, and (c) subjects who are either developing or have recently reached formal operational thinking.

Capie, Newton, and Tobin (1981); DeCarcer, Gabel, and Staver (1978); and Lawson (1985) have identified five formal modes of reasoning (i.e., proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning) as essential for science and mathematics achievement at the upper levels. The importance of proportional reasoning has been emphasized for both introductory and advanced science courses (Wollman and Lawson, 1978) and specifically in the application of quantitative relationships in science (Karplus, Karplus, Formisano, & Paulsen, 1979). In addition, they (Karplus et al., 1979) stressed the role of controlling variables in the understanding of cause-and-effect relationships. In addition, Hofstein and Mandler (1985) found that probability contributed significantly to the variance in physics and chemistry. Formal operational reasoning is a predictor of performance in chemistry (Howe & Durr, 1982), of the understanding of evolution concepts (Lawson, 1983b), and of science and mathematics achievement of eighth grade students (Bitner, 1986). Moreover, formal operations are vital in science and mathematics achievement as well as generalizable and necessary across the disciplines (Capie et al., 1981; Lawson, 1982a; Linn, 1982).

Formal operational thinkers outperformed transitional and concrete operational thinkers on abstract and concrete tasks. Formal operational high school chemistry students (Cantu & Herron, 1978); secondary biology, chemistry, and physics students (Lawson & Renner, 1975); ninth and tenth grade students in mathematics, chemistry, physics, and biology (Hofstein et al., 1985); propositional thinkers (Lawson, Lawson, & Lawson, 1984) outperformed transitional and concrete operational thinkers.

In general, males outperformed females on formal reasoning tasks (Farrell & Farmer, 1985; Hofstein et al., 1985; Meehan, 1984; Karplus et al., 1979). Meehan (1984) in a meta-analysis of fifty-three studies found that males scored significantly better than females on propositional logic, control of variables, and proportionality. Also, Hofstein et al. (1985) reported that males outperformed females on eight of the fifteen tasks on Lawson's test. In addition, low-income urban males performed better than females on control of variables and proportionality (Karplus et al., 1979).

Factors that impede or facilitate formal operational reasoning have been identified. Inhibitors of formal reasoning include field-dependency and superfluous information in a problem-situation (Lawson, 1982b, 1983a, 1983b; Lawson, 1985; Lawson & Snitgen, 1982; Levine & Linn, 1977; and Linn, 1980), impulsive cognitive style and low mental capacity (Lawson, 1985), and students' inaccurate expectations of variables and age (Linn, 1980; Linn, 1982; Linn, Clement, & Pulos, 1983). On the other hand, it has been found that concept familiarity (Champagne, Klopfer, & Anderson, 1980; Linn & Levine, 1978; Lazarowitz & Shemesh, 1986; Pulos & Linn, 1981) and task content and task problem (Lawson, 1982b, 1983a, 1983b; Linn, Pulos, & Gans, 1981) facilitated formal reasoning. Specifically, concrete physical models (Cantu & Herron, 1978; Gabel, 1979; Staver, 1984; Wollman & Lawson, 1978), inquiry laboratory approach in science concept achievement for concrete and formal operational thinkers (Gabel, 1979; Staver, 1984), and cognitive dissonance (Staver, 1984) have been recommended.

Research abounds on studies of logical thinking abilities. Until recently often the a paper-and-pencil format with actual demonstrations of the tasks (e.g., the Classroom Test of Formal Operations) was used (Lawson, 1978). The Group Assessment of Logical Thinking (GALT) (Roadrangka, Yeany, & Padilla, 1982) provides an alternative to the above format. The GALT is a paper-and-pencil instrument of logical thinking in which the examinees must respond correctly to both the answer and the reason. In the validation study, Roadrangka, Yeany, and Padilla (1983) found a reliability coefficient of .85 between the GALT and the Piagetian Interview Tasks. The principal components factor analysis resulted in factor loadings ranging between .33 to .73 with all items except the ones measuring conservation loading on Factor 1. Bitner (1986) reported that items #8 (proportional reasoning), #11 and #13 (controlling variables), #15 and #16 (probabilistic reasoning), #18 (correlational reasoning), #20 (combinatorial reasoning) loaded on Factor 1. Factor 1 contributed 19.3% of the total variance with all items except #18 loading .46 or greater. On Factor 2 items #1 and #4 (conservation), #9 (proportional reasoning), #17 (correlational reasoning), and #19 (combinatorial reasoning) loaded. Loadings on Factor 2 were .49 or greater except for item 1. Factor 2 contributed 14.9% of the variance. The two components extracted on the principal components varimax rotation explained 34.2% of the total variance. In this study of eighth grade students, Bitner (1986) found 5% functioning at the formal operational level, 33% functioning at the transitional level, and 62% functioning at the concrete level. Bitner (1986) reported that students in basic level and resource room were excluded from the sample. Premo and Fahey (1982) reported the percentage of formal level thinkers as follows: (a) 3.5% (seventh), (b) 5.2% (eighth), (c) 13.2% (ninth), (d) 44.7% (eleventh), and (e) 49.5% (twelfth). Karplus and Karplus (1970) reported the following percentages of complete abstract reasoners (N = 449) on the Island Puzzle: fifth and sixth graders (0%), seventh through ninth graders (0%), tenth through twelfth graders (3%), twelfth grade physics students (8%), 1969 NSTA Convention attendees (6%), and AAPT (13%). Karplus et al. (1979) concluded that students rarely use proportional reasoning before fifteen. In their sample of thirteen to fifteen years old students from seven countries, they (Karplus et al., 1979) found only 7% of the sample functioning at the formal operational level. In a sample of secondary biology, chemistry, and physics students (N = 133), Lawson et al. (1975) found only 4.8% of the sample were full formal operational reasoners. In a sample of students in grades seven through twelve (N = 588), Lawson and Renner (1974) found the following distribution in percentages: (a) formal: seventh (1%), eighth (3%), ninth (3%), tenth (5%), eleventh (8%), and twelfth (12%); (b) post concrete (transitional): seventh (15%), eighth (21%), ninth (13%), tenth (20%), eleventh (23%), and twelfth (21%); and (c) concrete: seventh (83%), eighth

(77%), ninth (82%), tenth (73%), eleventh (71%), and twelfth (66%).

In the use of the GALT, both Roadrangka et al. (1983) and Bitner (1986) found that the correlational and proportional reasoning items were the most abstract. In particular, Bitner (1986) noted that students had definite problems with item 8 (proportional reasoning), item 13 (controlling variables), item 15 (probabilistic reasoning), and items 17 and 18 (correlational reasoning). Only 20% of the sample (N = 147) used proportional reasoning for item 8; the others used additive or intuitive reasoning patterns. Forty-two percent of the sample (N = 147) used control of variables in the ramp problem. Non-formal thinkers reasoned that the heavy ball was needed because it had more force. Only 38% used probabilistic reasoning in the item 15. Those who selected the incorrect response and reason did not consider all dimensions of the problem (i.e., shape, texture, and number of geometric shapes). The percentages answering the correlational reasoning problems correctly are as follows: 21% (item 17) and 37% (item 18). Those students who responded incorrectly did not focus on the dimensions of the objects, and therefore did not glean the relationship. Furthermore, Bitner (1986) reported that 100% of the formal operational thinkers completed the correct combinations for items 19 and 20.

This researcher desired to determine the reasoning levels of seventh through twelfth grade students (N = 156) prior to the introduction of a thinking program of which logical thinking is one component.

The research questions investigated in this study include the following:

1. Is logical thinking a unitary construct as measured by the GALT?
2. What percentage of seventh through twelfth grade students are formal operational thinkers as measured by the GALT?
3. Are there significant differences in the level of thinking as measured on the GALT among seventh through twelfth grade students?
4. Are there gender differences in logical thinking ability of seventh through twelfth grade students as measured by the GALT?
5. What are the underlying differences in thinking among seventh through twelfth grade students classified as formal, transitional, or concrete operational?

Method

Sample

A convenience sample of all seventh through twelfth grade students (N = 156) in a consolidated school district in rural Arkansas was used. The researcher currently is a consultant in thinking skills for the district, K-12. The project is funded by the Winthrop Rockefeller Foundation.

Instrumentation

The instrument for this study was the abbreviated GALT a twelve-item paper and pencil test of logical thinking (Roadrangka et al., 1982). The fifty minute class periods necessitated the use of the abbreviated form of the GALT. The rationale for the selection of the GALT can be found in Roadrangka et al. (1983).

The twelve items in the abbreviated GALT measure six reasoning modes: conservation, proportional reasoning, controlling variables, probabilistic reasoning, correlational reasoning, and combinatorial reasoning. All reasoning modes except conservation require formal operational thinking.

Both construct and criterion-related validities have been established for the GALT (Roadrangka et al., 1983). In addition, a reliability coefficient of .85 was found between the GALT and the Piagetian Interview Tasks and for the GALT.

The GALT was administered to the sample within a one week span of time. The tests were then graded by a graduate assistant. Subsequently, the researcher rechecked the tests and assigned a total score ranging from 0-12. To receive credit for item 1, 4, 8, 9, 11, 13, 15, 16, 17, and 18, the subject had to select both the correct answer and the correct rationale. For item 19, the subject had to show a pattern and had to have not more than one error or omission. The subject had to show a pattern and had to have no more than two errors or omissions to receive credit for item 20.

The data were computed using statistical programs from Statistics with Finesse (Bolding, 1985)

Results

Included in the results section are the test analysis, descriptive statistics, and answers to the five research questions.

Test Analysis and Descriptive Statistics

The test analysis of the abbreviated GALT for the sample (N = 156) resulted in a range of proportion correct from .21 to .81 and discrimination indices ranging from .24 to .59 (see Table 1). All items discriminated in a positive direction. The analysis of the data for the total sample yielded a KR-20 reliability coefficient of .83. The KR-20 reliability coefficients for each grade are as follows: .70 (seventh), .81 (eighth), .69 (ninth), .87 (tenth), .82 (eleventh), and .85 (twelfth).

Insert Table 1 about here

In Table 2 are contained the mean, standard deviation, and percent on the GALT for the seventh through twelfth grade students. The mean of the six grade levels ranged between 1.52 and 5.22. The mean of the tenth grade group (*M* = 5.22, *SD* = 3.30) exceeded all other groups in the sample.

Insert Table 2 about here

Intercorrelations and Principal Components Analysis

The intercorrelation matrix for the six modes of reasoning and the total GALT score in Table 3 yielded coefficients ranging between .17 and .78. The highest correlations coefficients were found between the GALT total score and proportional reasoning (.71), probabilistic reasoning (.78), and combinatorial reasoning (.70).

Insert Table 3 about here

The principal components factor analysis of the twelve items in the abbreviated GALT resulted in a two factor solution. All items except the two which measure conservation loaded on factor one. Seven of the twelve values on Factor 2 were negative. Subsequently, the principal components factor varimax rotation analysis of the twelve items in the abbreviated GALT was completed (Cattel, 1978; Kim & Mueller, 1978). The varimax rotation analysis of the twelve items in the abbreviated GALT resulted in a two factor solution (see Table 4). In this study, items 8 and 9 (proportional reasoning), item 11 (controlling variables), items 15 and 16 (probabilistic reasoning), items 17 and 18 (correlational reasoning), and items 19 and 20 (combinatorial reasoning) loaded on Factor 1 with loadings between .37 and .88. Factor 1 contributed 30% of the variance. Item 1 (conservation of mass), item 4 (conservation of volume), and item 13 (controlling variables) loaded on Factor 2 with loadings ranging between .56 and .80. Therefore, Factor 2 contributed 14.5% of the variance. The two components extracted on the principal components factor varimax rotation explained 44.5% of the total variance. Also, included in Table 4 are the broad variance (h^2) and unique variance (U^2) for the twelve items in the abbreviated GALT.

Insert Table 4 about here

The six reasoning modes were then subjected to the single-factor solution. The loadings ranged between .47 and .81 with all loadings except those for conservation loading at or beyond .68. The single-factor solution of the six reasoning modes explained 47.4% of the variance.

<u>Reasoning Levels of Seventh through Twelfth Graders</u>

The percentages of students falling in the formal operational level per grade are as follows: (a) 0% seventh grade students, (b) 4% eighth grade students, (c) 3% ninth grade students, (d) 22% tenth grade students, (e) 12% eleventh grade students, and (f) 28% twelfth grade students. The percentages of students falling in the transitional operational level per grade are as follows: (a) 4% (seventh), 26% (eighth), 17% (ninth), 28% (tenth), 31% (eleventh), 6% (twelfth). In addition, the percentages of concrete operational students per grade are as follows: 96% (seventh), 70% (eighth), 80% (ninth), 50% (tenth), 58% (eleventh), 67% (twelfth). The percentages of each reasoning level for the total sample are 11% formal, 19% transitional, and 70% concrete.

Insert Table 5 about here

Differences in Reasoning Levels Among the Seventh through Twelfth Grade Students

Differences in reasoning levels among the seventh through twelfth grade students were found. The results of the t-test of independent samples (see Table 6) indicated that the senior high group (i.e., students in grades ten through twelve) surpassed the junior high group (i.e., students in grades seven through nine) on individual reasoning items, subtests, and GALT total. In addition, the result of the one-way analysis of variance (grade level by GALT) is reported in Table 7.

Insert Tables 6 and 7 about here

Gender Differences in Logical Thinking Ability of the Seventh through Twelfth Grade Students

Although gender differences were limited in this study, significant differences were found on individual items. The males outperformed the females on the conservation item metal weights and on the probabilistic reasoning item squares and diamonds #2. The females outperformed the males on the combinatorial reasoning item the dance.

Insert Tables 8 about here

<u>The Underlying Differences in Thinking among Seventh through Twelfth Grade Students</u>

The researcher decided to examine more closely the responses and reasons for those items for which the percentage of incorrect answers and reasons surpassed the percentage of correct answers and reasons. In particular, both the answers and reasons for Items 8, 11, and 17 and only the answers for Items 15, 16 and 18 were scrutinized for patterns of transitional and concrete operational thinkers. A closer observation of the results of Item 20 indicated that only four formal operational thinkers selected the incorrect answer. Again patterns were found.

For item 8 a proportional reasoning problem measuring ratio of water levels, only 27% of the sample (N = 156) selected the correct response c, whereas 40% of the sample chose the incorrect response a and 21% of the sample selected b. Both response a and b represent addictive thinking. The pattern of correct response for item 8 per grade level is as follows: 15% for seventh, 5% for eighth, 10% for ninth, 3% for tenth, 4% for eleventh, and 22% for twelfth. The percentage of students selecting either response a or b per grade level is as follows: 78% for seventh, 55% for eighth, 57% for ninth, 36% for tenth, 42% for eleventh, and 44% for twelfth. An examination of the item per level of thought reveals the following patterns: 77% of the formal, 50% of the transitional, and only 13% of the concrete chose the correct response c. Eighteen percent of the formal operational reasoners selected a and 65% of them chose b. Of the transitional operational thinkers, 37% selected a and none of them selected b. Forty-four percent of the concrete operational reasoners selected a; 29% chose b.

The justification for item 8 also created difficulty for the examinees. Only 21% of the sample (N = 156) selected the corrected reason 2, whereas 33% selected reason 1, 26% selected reason 3 and 18% selected reason 4. The response pattern for the correct reason per grade level is as follows: 41% of the seventh graders, 5% of the eighth graders, 13% of the ninth graders, 50% of the tenth graders, 28% of the eleventh graders, and 22% of the twelfth graders. The percentages selecting the correct reason per reasoning level are as follows: 65% of the formal, 43% of the transitional, and 8% of the concrete. The percentages per reasoning level choosing the reason 1 (additive reasoning) are as follows: 18% of the formal, 20% of the transitional, and 39% of the concrete. Reason 3 (intuitive reasoning) was selected by 6% of the formal operational thinkers, 10% of the transitional operational thinkers, and 33% of the concrete operational thinkers. Those selecting "There is no way of predicting" are 6% of the formal, 23% of the transitional, and 18% of the concrete.

Only 42% of the sample (N = 156) selected the correct response c for item 11 the pendulum, a controlling variables problem. The others answered 23% response d (doesn't understand control), 13% response a (are not controlling for weight), and 10% for response b and 11% for e (both do not indicate an understanding of controlling variables). The percentage of the correct response per grade level are as follows: 20% for seventh graders, 44% for eighth graders, 41% for ninth graders, 65% for tenth graders, 36% for eleventh graders, and 40% for twelfth graders. The following patterns were found for the three levels of reasoning: (a) 94% of the formal, 67% of the transitional, and 27% of the concrete chose the correct response c. (b) Response a was selected by 6% of the formal, 7% of the transitional, and 16%

of the concrete. (c) Only 8% of the concrete operationals selected response b. (d) Twenty percent of the transitional and 28% of the concrete operationals selected d. (e) Only 16% of the concrete chose response e.

Forty-six percent of the sample (N = 156) selected the correct reason 5 for item 11, a controlling variables problem. Twenty-two percent chose 2 (a lack of understanding of the relationship between manipulation and control), thirteen percent chose 3 (doesn't understand manipulation or control), 10% chose 4 (doesn't realize the need for comparison of manipulated variable length), 8% chose 1 (doesn't consider manipulation of the length), and no reason (2%). The percentages of the correct reason per grade level are as follows: 33% (seventh), 47% (eighth), 45% (ninth), 75% (tenth), 39% (eleventh), and 11% (twelfth). The correct reason 5 was chosen by 100% (formal), 73% (transitional), and 29% (concrete). Reason 3 was selected by 13% of the transitional and 16% of the concrete. Justification 2 was chosen by 7% of the transitional and 30% of the concrete. Three percent of the transitional and 14% of the concrete operational thinkers chose reason 4. Only 11% of the concrete operational thinkers selected reason 1.

Only 27% of the sample (N = 156) selected the correct response a for item 15, a probabilistic reasoning problem. Twenty-nine percent chose answer e (other), 22% selected d (did not consider the dimensions of color and shape), 17% selected 3 (only considered one dimension--spotted), and 5% chose b. The percentages of correct response per grade level are as follows: 8% (seventh), 31% (eighth), 16% (ninth), 50% (tenth), 27% (eleventh), and 39% (twelfth). One hundred percent of the formal level thinkers, 47% of the transitional operational thinkers, and only 10% of the concrete operational thinkers chose the correct response a. Response e was selected by 37% of the transitional operationals and 31% of the concrete operationals. Response c was chosen by 13% of the transitional and 20% of the concrete. Three percent of the transitional thinkers and 6% of the concrete reasoners selected b. Only 32% of the concrete operational thinkers chose d.

Only 24% of the sample (N = 156) selected the correct response a for item 16, a probabilistic reasoning problem. Thirty-nine percent of the sample selected e (other), 13% chose d (considered only number of diamonds and total number of objects), 12% chose b (considered only diamond shape), 12% chose c (considered only number, not shape or texture), and 1% (no response). Per grade level, 4% (seventh), 23% (eighth), 13% (ninth), 44% (tenth), 27% (eleventh), and 33% (twelfth) responded correctly to item 16. According to the levels of reasoning, 94% of the formal, 43% of the transitional, and 8% of the concrete selected the correct response a. Response e was selected by the formal operational thinkers (6%), by the transitional (47%), and by the concrete (42%). Seven percent of the transitional and 17% of the concrete selected d. Three percent of the transitional and 16% of the concrete chose b. Only 17% of the concrete operational thinkers selected c.

For item 17 a correlational reasoning problem (mice), 40% of the sample (N = 156) selected the correct response a, whereas 58% chose b. Per grade level, 59% (seventh), 35% (eighth), 17% (ninth), 34% (tenth), 46% (eleventh), and 28% (twelfth) chose the correct response a, indicating there is a relationship between the size of the mice and the color of their tails.

The justification for item 17 seemed also to create a problem for the students. Only 19% of the sample (N = 156) chose the correct reason 1. Thirty-six percent selected 2 (observed only the color of the tails and the size of the mice without any reference to how size and color are related in the problem), 6% chose 4 (considered only one dimension of the problem--tail color), and 55% selected 5 (considered only the dimension of size). The percentages of correct reason by grade level are as follows: 15% (seventh), 22% (eighth), 10% (ninth), 28% (tenth), 23% (eleventh), and 11% (twelfth). Eighty-two percent of the formal operational reasoners, 20% of the transitional, and only 8% of the concrete selected the correct justification 1. Reason 3 was selected by 6% of the formal operationals, by 40% of the transitionals, and by 38% of the concrete. Six percent of the formal, 37% of the transitional, and 40% of the concrete selected reason 2. Reason 4 was chosen by 6% of the concrete. Only 7% of the concrete reasoners chose reason 5.

The rationale for item 18 (fish), a correlational problem seemed to be a difficult for the students. Only 7% of the sample (N = 156) chose the correct reason 2. Forty-seven percent selected 1 (observed only the size of the fish and the width of the stripe without reference to the relationship between the two characteristics), 35% chose 4 (observed only that not all fish are the same in respect to stripes and size), 6% selected 5 (considered only the stripes, not the size), and 4%

selected 3 (considered only the size of the fish). The percentages of the correct reason per grade level are as follows: 4% (seventh), 9% (eighth), 7% (ninth), 6% (tenth), 12% (eleventh), and 6% (twelfth). Only 12% of the formal, 13% of the transitional, and 5% of the concrete selected the correct rationale 2. Forty-one percent of the formal, 53% of the transitional, and 46% of the concrete chose 1. Twenty-nine percent of the formal, 33% of the transitional, and 37% of the concrete chose 3. Reason 5 was chosen 12% by the formal and 75% by the concrete.

Forty-four percent of the sample (N = 156) listed the correct number of pairs of dancing partners for item 19, a combinatorial reasoning problem. The formal operational students scored 100% on this item. The percentages per grade level listing the correct number of dancing partners are as follows: 30% (seventh), 48% (eighth), 20% (ninth), 59% (tenth), 54% (eleventh), and 56% (twelfth). The most frequent error was the repeating of the partners (i.e., A-L and L-A).

For item 20, a combinatorial reasoning problem, only 21% of the sample (N = 156) managed to complete the twenty-four combinations. Even four of the formal operational reasoners (n = 17) failed to complete the twenty-four patterns. The percentages per grade level completing the patterns are as follows: 0% (seventh), 13% (eighth), 30% (ninth), 22% (tenth), 27% (eleventh), and 39% (twelfth). Three of the four formal operational students who missed item 20 were males. One male completed just fours sets of four or sixteen total. Another male completed four sets of three or twelve total. The third male began with a set of four then went to sets of three, and finally returned to the sets of four. The female student did not consider all combinations at the onset, did not complete the pattern, and had no real pattern. The concrete operational students rarely had a pattern and either completed too few combinations or tried to fill all the blank spaces.

Discussion and Educational Implications

Both similarities and differences exist between the results of this study and the results of other studies in which the GALT was utilized (e.g., Bitner, 1986; Roadrankga et al., 1983). The test reliability for this sample was similar to Roadrankga et al.'s (1983) reliability for the total GALT, but slightly lower than Bitner's (1986). Also, the results of the principal components varimax rotation differ only slightly from those of Roadrangka et al. (1983) and drastically from Bitner's (1986). In the present study, only one formal reasoning item (i.e., item 13) failed to load on Factor 1. Of course, this sample which included students in Grades 7-12 was similar to Roadrankga et al.'s (1983) sample which ranged from sixth grade students through graduate level college students, but differed from Bitner's (1986) sample of eighth grade students.

The proportion of students (11%) in this sample (N = 156) classified as formal operational reasoners was higher than those reported by Karplus et al. (1970), Lawson et al. (1974), and Lawson et al. (1975) and lower than Premo et al's (1982) findings. In particular, the percentage of tenth (22%) and twelfth (28%) grade students who are functioning at the formal operational level is high.

In addition, obvious differences in reasoning exist between formal and non-formal operational thinkers. In the proportional reasoning problems, the concrete and transitional operational thinkers used additive or intuitive reasoning rather than ratios to solve the problems. In the control of variable problems, the transitional and concrete operational reasoners did not indicate an understanding of the relationship between manipulation and control. In solving the probabilistic reasoning problem, the concrete and transitional operational thinkers focused on only one or two dimensions of the problem (i.e., geometric shape diamond and number of diamonds). The concrete and transitional operational students failed to observe the characteristics of the objects and to understand the relationship between the characteristics in the correlational reasoning problems. The non-formal operational students failed to demonstrate a pattern and did not complete all combinations in the combinatorial logic problems.

The results of this study indicated that only 11% of the students in grades seven through twelve are formal operational thinkers and yet many scientific concept, laws, and principles require logical thought processes (Bitner, 1986; Capie et al., 1981; DeCarcer et al., 1978; Hofstein et al., 1985; Howe et al., 1982; Karplus et al., 1979; Lawson, 1982a, 1983b, 1985; Linn, 1982; Wollman et al., 1978). If our goal for the 21st century is a scientifically and technologically literate society (James et al., 1985; National Science Board Commission, 1983; Yager, 1984), intervention approaches are needed to bridge the gap between the thought processes of concrete and transitional operational thinkers and the demands of abstract scientific concepts, laws, and principles.

Recommendations for bridging the gap include the use of tuning (Linn, 1982), the use of concrete physical models (Cantu et al., 1978; Gabel, 1979; Staver, 1984), the use of the inquiry approach (Gabel, 1979; Staver, 1984), and the use of cognitive dissonance (Staver, 1984).

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Table 1

Test Analysis of the Abbreviated GALT (N = 156)

Item	Proportion Correct	Discrimination Index	Mean	Standard Deviation
Mode 1: Conservation				
#1 Piece of Clay	.81	.45	.78	.41
#4 Metal Weights	.58	.46	.54	.50
Subtest: Conservation (#1 and #4)	.70			
Mode 2: Proportional Reasoning				
#8 Glass Size #2	.24	.52	.15	.36
#9 Scale #1	.50	.58	.31	.46
Subtest: Proportional Reasoning (#8 and #9)	.37			
Mode 3: Controlling Variables				
#11 Pendulum Length	.44	.58	.37	.48
#13 Ball #1	.50	.55	.41	.49
Subtest: Controlling Variables (#11 and #13)	.47			
Mode 4: Probabilistic Reasoning				
#15 Squares and Diamonds #1	.39	.59	.21	.41
#16 Squares and Diamonds #2	.40	.56	.20	.40
Subtest: Probabilistic Reasoning (# 15 and #16)	.40			
Mode 5: Correlational Reasoning				
#17 The Mice	.30	.37	.15	.36
#18 The Fish	.38	.24	.03	.16
Subtest: Correlational Reasoning	.34			
Mode 6: Combinatorial Reasoning				
#19 The Dance	.44		.44	.50
#20 The Shopping Center	.21		.21	.41
Subtest: Combinatorial Reasoning	.33			

Note 1. KR-20 (N = 156) = .83. The KR-20 reliability coefficients for each grade are .70 (seventh), .81 (eighth), .69 (ninth), .87 (tenth), .82 (eleventh), and .85 (twelfth).

Table 2

Mean, Standard Deviation, and Percent on the GALT for 7th through 12th Grade Students Answering Each Item Correctly (N=156)

Reasoning Skill	7 (n=27)			8 (n=23)			9 (n=30)			10 (n=32)			11 (n=26)			12 (n=18)			Total (N=156)		
	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%	M	SD	%
Con	.78	.75		1.35	.78		1.50	.68		1.53	.62		1.31	.74		1.28	.75		1.30	.75	47
#1	.52	.51	52	.83	.39	83	.90	.31	90	.94	.25	94	.69	.47	69	.78	.43	78	.78	.41	78
#4	.26	.45	26	.52	.51	52	.67	.48	67	.59	.50	59	.62	.50	62	.61	.50	61	.54	.50	54
Prop Reas	.07	.27		.17	.49		.50	.68		.75	.84		.62	.70		.67	.69		.47	.69	11
#8	.00	.00	0	.04	.21	4	.10	.31	10	.38	.49	38	.19	.40	19	.17	.38	17	.15	.36	15
#9	.07	.27	7	.13	.34	13	.40	.50	40	.38	.49	38	.42	.50	42	.44	.51	44	.31	.46	31
Cont Var	.22	.58		.65	.78		.83	.75		1.09	.73		.96	.77		.83	.91		.78	.79	22
#11	.11	.32	11	.39	.50	39	.40	.50	40	.59	.50	59	.31	.47	31	.33	.49	33	.37	.48	37
#13	.11	.32	11	.26	.45	26	.43	.50	43	.50	.51	50	.65	.49	65	.50	.51	50	.41	.49	41
Prob Reas	.07	.38		.26	.62		.17	.53		.75	.95		.54	.90		.67	.91		.40	.78	18
#15	.04	.19	4	.13	.34	13	.07	.25	7	.38	.49	38	.27	.45	27	.39	.50	39	.21	.41	21
#16	.04	.19	4	.13	.34	13	.10	.31	10	.38	.49	38	.27	.45	27	.28	.46	28	.20	.40	20
Correl Reas	.07	.27		.17	.49		.10	.31		.28	.52		.23	.43		.11	.32		.17	.41	1
#17	.07	.27	7	.13	.34	13	.10	.31	10	.25	.44	25	.19	.40	19	.11	.32	11	.15	.36	15
#18	.00	.00	0	.04	.21	4	.00	.00	0	.03	.18	3	.08	.27	8	.00	.00	0	.03	.16	3
Comb Reas	.30	.47		.61	.72		.43	.57		.81	.78		.85	.73		.94	.87		.64	.72	14
#19	.30	.47	30	.48	.51	48	.20	.41	20	.59	.50	59	.54	.51	54	.56	.51	56	.44	.50	44
#20	.00	.00	0	.13	.34	13	.30	.47	30	.22	.42	22	.27	.45	27	.39	.50	39	.21	.41	21
GALT Total	1.52	1.65		3.26	2.42		3.63	1.90		5.22	3.30		4.50	2.77		4.50	3.20		3.78	2.83	

Table 3

Intercorrelations Among Subtests of Formal Reasoning on GALT for 7th through 12th Grade Students

	1	2	3	4	5	6	7
1. Conservation	1.00						
2. Proportional Reasoning	.25	1.00					
3. Controlling Variables	.33	.41	1.00				
4. Probabilistic Reasoning	.26	.53	.40	1.00			
5. Correlational Reasoning	.17	.30	.38	.54	1.00		
6. Combinatorial Reasoning	.18	.41	.40	.50	.36	1.00	
7. Total GALT	.55	.71	.73	.78	.60	.70	1.00

Table 4

Factor Structure Loading for GALT Items

	Principal Components Varimax Rotation					
	Two Factor		Broad	Unique	Single Factor	
Reasoning Mode	F1[a]	F2[b]	h^2[c]	U^2[d]	Loading/Commun	
#1 Conservation of Mass		.80	.64	.36		
#4 Conservation of Volume		.67	.45	.55	.47	.22
#8 Proportional Reasoning	.68		.49	.51		
#9 Proportional Reasoning	.41		.30	.70	.72	.51
#11 Controlling Variables	.45		.32	.68		
#13 Controlling Variables		.56	.43	.57	.71	.50
#15 Probabilistic Reasoning	.88		.78	.22		
#16 Probabilistic Reasoning	.86		.74	.26	.81	.66
#17 Correlational Reasoning	.70		.49	.51		
#18 Correlational Reasoning	.37		.14	.86	.68	.46
#19 Combinatorial Reasoning	.46		.23			
#20 Combinatorial Reasoning	.55		.33	.67	.71	.50
Eigenvalues	3.60	1.75	5.35	.72	2.85	2.85

Note. Eigenvalue > 1.00.
[a]30% of the variance.
[b]14.5% of the variance.
[c]44.5% of variance
[d]$U^2 = 1-h^2$.

Table 5

Proportion of Students According to the Level of Reasoning as Measured on the GALT and Gender for 7th through 12th Grade Students

Grade	Level of Reasoning					
	Formal[a]		Transitional[b]		Concrete[c]	
	F	%	F	%	F	%
7th (n=27)	0	0	1	4	26	96
Male (n=12)	0	0	0	0	12	44
Female (n=15)	0	0	1	4	14	52
8th (n=23)	1	4	6	26	16	70
Male (n=14)	1	4	4	17	9	39
Female (n=9)	0	0	2	9	7	30
9th (n=30)	1	3	5	17	24	80
Male (n=17)	0	0	2	7	15	57
Female (n=13)	1	3	3	10	9	30
10th (n=32)	7	22	9	28	16	50
Male (n=18)	4	13	4	13	10	31
Female (n=14)	3	9	5	16	6	19
11th (n=26)	3	12	8	31	15	58
Male (n=13)	3	12	4	15	6	23
Female (n=13)	0	15	9	35	13	50
12th (n=18)	5	28	1	6	12	67
Male (n=11)	4	22	0	0	7	39
Female (n=7)	1	6	1	6	5	28
Total (N=156)	17	11	30	19	109	70

[a]Formal = Level 3, score 9-12; M = 9.76, SD = 0.97.
[b]Transitional = Level 2, score 5-8; M = 6.03, SD = 1.10.
[c]Concrete = Level 1, score 0-4; M = 2.23, SD = 1.26.

Table 6

Comparison of Junior High Students (n = 80) and Senior High Students (n = 76): Individual Items, Subtests, and GALT Total

Item Reasoning Skill	t-value	p
1 Piece of Clay	.9916	.1615
4 Metal Weights	1.4772	.0708
Subtest: Conservation	1.5265	.0645
8 Glass Size #1	3.8356	.0001
9 Scale #1	2.6868	.0040
Subtest: Proportionality	4.0243	.0000
11 Pendulum Length	1.7458	.0414
13 Ball #1 (Ramp)	3.6493	.0002
Subtest: Controlling Variables	3.3533	.0002
15 Squares and Diamonds #1	4.3476	.0000
16 Squares and Diamonds #2	3.7033	.0001
Subtest: Probabilistic Reasoning	4.1877	.0000
17 The Mice	1.7198	.0437
18 The Fish	1.0624	1.1449
Subtest: Correlational Reasoning	1.7164	.0440
19 The Dance	3.2770	.0006
20 The Shopping Center	1.9418	.0270
Subtest: Combinatorial Reasoning	3.7856	.0001
GALT Total	4.6738	.0000

Note 1. The means of the senior high students surpassed the means of the junior students on all variables.

Table 7

One-Way Analysis of Variance: Grade Level by GALT

Source	DF	SS	MS	F	p
Among	5	241.48	48.30	7.21	.0000
Within	149	997.92	6.70		
Total	155	1239.39			

Table 8

Comparison of Males' and Females' Scores for 7th through 12th Grade Students on the Subtests and Individual Items of the GALT

Item Reasoning Skill	Significant and non-significant differences ($p < 0.01$)
Conservation	Males > Females
1 Piece of Clay	N.S.
4 Metal Weights	Males > Females
Proportional Reasoning	N.S.
8 Glass Size #1	N.S.
9 Scale #1	N.S.
Controlling Variables	N.S.
11 Pendulum Length	N.S.
13 Ball #1	N.S.
Probabilistic Reasoning	N.S.
15 Squares and Diamonds #1	N.S.
16 Squares and Diamonds #2	Males > Females
Correlational Reasoning	N.S.
17 The Mice	N.S.
18 The Fish	N.S.
Combinatorial Reasoning	N.S.
19 The Dance	Females > Males
20 The Shopping Center	N.S.
GALT Total	N.S.