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ABSTRACT

Recently, a number of studies have reported a high correlation between the supposedly separate traits described as integrated science process skills and formal reasoning ability. The implication has been that these two constructs are different but related. Further implications have been made that a treatment to enhance one "trait" might influence the other as a result of some cause-effect relationship. This study measured these two attributes using different instruments to assess their discriminant and convergent validity. The instruments used were the Classroom Test of Formal Operations (Lawson) and the Group Assessment of Logical Thinking (GALT) to measure formal reasoning, the Test of Integrated Process Skills (TIPS II) and the Process Skills of Science Test (PSS) to measure integrated science process skills. Results indicate that the two traits share more variance than expected and that they may not comprise distinctly different traits. A factor analysis was performed on subtest intercorrelations to examine which, if any, subfactors on the two constructs overlapped. Overlap was indicated for the subfactors of controlling variables, probabilistic reasoning, and combinatorial reasoning. (Author/JN)

Validity Considerations for the Study of Formal Reasoning Ability and Integrated Science Process Skills

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Recent papers (Tobin and Capie, 1982; Dillashaw and Okey, 1980) have indicated a high correlation (0.71 Pearson *r*) between integrated science process skills as defined by the American Association for the Advancement of Science (AAAS, 1967) and formal reasoning ability as measured by pencil and paper versions of the Piagetian interview. One paper (Padilla, Okey and Dillashaw, 1983) called for investigation of a cause-effect relationship between integrated science process skills and formal reasoning ability. A more recent study (Padilla, Okey and Garrard, 1984) searched for effects on integrated science process skills and formal reasoning ability resulting from the same treatment. No measurable effect on formal reasoning ability was detected, despite significant gains in process skills.

It would seem reasonable to consider whether integrated science process skills and formal reasoning ability are separate traits, or perhaps manifestations of some third trait such as general intellect. If they are indeed separate traits, the consistent high correlation between them has implications for science teaching and curriculum design. If by enhancing one through effective teaching, the related trait is acquired to a measurably greater degree, then efforts to manipulate teaching styles, inquiry activities, and learning modes which advance the 'driver' trait would be warranted.

However, if the two traits are to a large extent one and the same, then efforts to connect them in cause-effect relationships would not be indicated.

One implication might be that both may be caused by some third attribute which should be studied or manipulated. Methods now used to enhance formal reasoning might then be equally applicable for promoting science process skills, and vice versa. Research directions would be altered by this finding.

Review of Related Research

Lawson (1978) reported finding three principal factors when his test of formal reasoning was subjected to principal-component analysis. These three factors accounted for 66% of the total variance. Test items involving proportions, control of variables, combinational reasoning and probability loaded heavily on the same factor. He identified this factor as "formal reasoning", a second factor as "early formal reasoning", and a third as "concrete" reasoning". From this he concluded that his test had factorial validity.

Roadrangka, Yeany and Padilla (1983) found low to moderate (.30 to .70) intercorrelations among six subfactors of their Group Assessment of Logical Thinking test. Their factor analysis identified a two-factor solution, with conservation of mass items loading on one factor and all others loading on a single primary factor, indicating that separate scores for the six subfactors may not be warranted. It may also indicate the absence of separate subtraits of logical thinking.

Lawson and Snitgen (1982) reported that formal reasoning among preservice elementary teachers could be enhanced by a one-semester biology course which emphasized development of formal reasoning strategies. No specific science process skills were emphasized in their treatment. They found evidence of a "psychological set" in how individuals visualize and respond to a problem situation requiring formal reasoning. There was little evidence of transfer for the trained components of formal reasoning to novel situations.

Padilla, Okey and Dillashaw (1983) examined integrated science process skills and formal thinking abilities of 500 middle and high school students. They reported a correlation of .73 between the two traits. However, their factor analysis of the scores found that one common factor accounted for 37.4% of total variation in scores. They found that each subtest of both the process skills and logical thinking tests correlated from .50 to .71 with the single factor. They concluded that "the fact that a single factor was identified to which all subtests of logical thinking and process skill tests contribute is strong evidence for a common underlying construct."

Padilla, Okey and Garrard (1984) used a model for generating integrated science process skills as a treatment for 6th and 8th grade students over a 14-week period. The model involved seven steps as follows:

1) The teacher poses a question which can be investigated;
2) Students form several appropriate hypotheses;
3) Students identify variables using brainstroming techniques;
4) Manipulated and responding variables are selected and operationally defined, along with methods of control;
5) Students design the experiment and construct a table for data;
6) Groups of students conduct the experiment;
7) Students organize the data and make generalizations to test the original hypotheses and/or reach tentative conclusions.

They examined both integrated process skills and logical thinking after treatment, and found no significant changes in logical thinking due to the treatment. Although 6th graders showed no significant process skill changes, 8th grade subjects showed significant gains. They concluded that "Either process skill instruction is not a means of influencing growth in logical thinking or the period of time devoted to that pursuit must be extended before effects are evident."

Yeany, Yap and Padilla (1984) searched for hierarchical relationships among formal reasoning ability and integrated science process skills using task analysis. This method involved identifving a terminal skill and working backward through levels of prerequisite skills learners must have in order to achieve the terminal skill. Subjects were 741 high school science students in grades 7 to 12. They concluded that the skills of combinatorial reasoning, conservation reasoning and designing experiments form the base of a hierarchy of skills. Subjects who have mastered these base skills are more likely to master higher skills. Their model combines all of the formal reasoning ability skills with all of the integrated science process skills into a single tree structure. At the top of their model are identifying variables and correlational reasoning, both of which supposedly require all the prerequisite skills beneath. Their effort made no attempt to isolate the skills into separate traits.

Procedure

There is a statistical method for examining the independence of two or more traits, provided at least two separate test instruments can be found to measure each trait (Campbell and Fiske, 1959). The process involves testing each trait by separate methods and then comparing the correlations between different measures of the same trait with correlations of (a) different traits measured by the same method, and (b) different traits measured by different methods. The result is a multitrait-multimethod matrix, in which consistently higher correlations should be obtained when (a) the same trait is measured by the same method, than when (b) the same trait is measured by different methods, than when (c) different traits are measured by the same method, than when (d) different traits are measured by different methods.

Two independent tests of the AAAS (1967) science process skills were located. One was produced by researchers at the University of Georgia (Dillashaw and Okey, 1980), and the other by a doctoral student at the University of Connecticut (Burns, 1972). Similarly, two independent tests of formal reasoning ability were obtained. One of these was developed at the University of Georgia (Roadrangka, Yeany and Padilla, 1983); the other was produced by Dr. Anton Lawson (Lawson, 1978).

Fifty-four subjects from three educational psychology classes for preservice elementary education majors volunteered to take all four tests in two sittings. The two Georgia tests (Dillashaw and Okey, 1980; Roadrangka, Yeany and Padilla, 1983) were given in one sitting in an attempt to replicate the reported correlations between integrated science process skills and formal reasoning ability. After one week the other two tests (Burns, 1972; Lawson, 1978) were given in one sitting. No intervening treatment was provided, and none of the subjects were taking a science methods course.

Table 1 describes the four tests used to establish the multitrait-multitest matrix.

Insert Table 1 about here

The subfactors of the two tests measuring formal reasoning are identical except that the GALT test (Roadrangka, Yeany and Padilla, 1983) adds conservation to the basic five subfactors: controlling variables, combinational reasoning, correlational reasoning, probabilistic reasoning, and proportional reasoning. The integrated science process skill subfactors are: controlling variables, interpreting data, formulating hypotheses, defining operationally, and experimenting. Both traits share the subfactor controlling variables.

The first step in the multitrait-multitest procedure was to obtain published test-retest reliabilities of the four tests for the same trait-same method correlation. Since test-retest reliabilities use the same method to measure a single trait, they were expected to be higher than correlations involving the same trait measured by different methods, different traits measured by the same method, and different traits measured by different methods.

Next, the same trait-different method correlations were examined. These correlations were obtained by correlating the same trait measured by two different methods. If the same trait-different method correlations are high and significant from zero, the traits are said to possess convergent validity, since both tests converge to produce a high correlation irrespective of method.

Discriminant validity was examined with two additional comparisons. First, the correlation between the same trait measured with different methods was compared with the correlation between different traits measured with the same method. If a trait possesses discriminant validity, the former correlation will be higher than the latter, since the same trait, even though measured by different methods, should have more in common than different traits that happen to employ the same method. Lastly, the same trait-different method correlations were compared with the different trait-different method correlations. Here the difference between the two sets of correlations should be even larger than in the previous comparison, since neither traits nor methods are in common.

Results

A summary table of test results is shown in Table 2. Table 3 shows the multitrait-multitest matrix resulting from the intercorrelations among the four tests.

Insert Table 2 and Table 3 about here

Although different trait-same method correlations could not be obtained with these tests, it can be noted that the same trait-different test correlation with the TIPS II and PSST measures (.62) is identical to the different trait-different test correlation with the TIPS II and GALT measures (.62). The reason why the correlation between different traits measured by two different tests would be as high as the correlation between the same trait measured by two different tests is of interest. One interpretation is that the correlation between the TIPS II test of process skills and the GALT test of formal reasoning was inflated by the similarity in testing format. The traits being measured by the TIPS II and GALT tests both use a multiple choice format (see Table 1), which may have contributed to their shared variance. This may account for the poor discriminant validity for the integrated science process skills trait.

Another indication of the possible susceptibility of the GALT and TIPS II scores to variance due to testing method comes from the correlation between the Lawson test of formal reasoning and the PSST test of integrated science process skills. Contrary to the TIPS II and GALT, which use almost identical formats, the Lawson test uses a videotape format while the PSST uses a paper and pencil format. The different trait-different test correlation between Lawson and PSST was .52 (different formats), while the different trait-different test correlation between the GALT and TIPS II was .62 (similar formats). This difference suggests that shared variance between the GALT and TIPS II could have been due to a similar testing format or "method."

The high correlation between the TIPS II and the GALT tests might also be the result of a common philosophical and/or theoretical orientation among test authors. Both tests, although authored by different sets of individuals, were constructed by science educators working within the same research environment. A particular orientation to science education operating within this environment could have lessened the theoretical distinctions between test development projects.

It is interesting to note that the multitrait-multitest data do not indicate a similar discriminant validity problem for the Lawson and PSST tests. These tests did not employ similar formats and were not developed by individuals working within the same professional context. The different trait-different test correlation between the Lawson test of formal reasoning and the PSST test of integrated science process skills was .52, while the same trait-different test correlation between the GALT test of formal reasoning and the Lawson test of formal reasoning was .65. The difference here is in the expected direction, indicating good discriminant validity.

The next step in studying the relationship between integrated science process skills and formal reasoning, would be to perform a factor analysis on the subscale scores of the TIPS II and GALT tests. This analysis could determine if the five subfactors of the TIPS II, measuring integrated science process skills, load on one factor and the five factors of the GALT, measuring formal reasoning, on another factor. The size of the data base for the present study, however, was insufficient for such an analysis to be performed. The authors looked for other data bases on which such an analysis could be performed. A paper by Roadranka, Yeany and Padilla (1983) reported intercorrelations among subscales of the GALT (N=628, grades 6 through college level science methods) and between subscales of the GALT and TIPS (N=550, grades 6 and 8). It did not, however, provide intercorrelations among subscales of the TIPS II which would be needed before a factor analysis could be performed.

The authors then located a third unpublished data base providing the raw data from which the third set of intercorrelations could be obtained. This study was conducted for the Austin, Texas Independent School District, which obtained data from 506 high school students who took the TIPS II as part of a curriculum evaluation project during the spring of 1984.

All three sets of correlations together provided the opportunity to factor analyze the subscale scores of the TIPS II and GALT to determine if any overlap existed in the subconstructs they measured. The factor analysis was initiated with the intercorrelations provided by these three data bases. The intercorrelations among the ten subscales (5 each from TIPS and GALT) appear in Table 4. The Kaiser Varimax rotated factor loadings appear in Table 5.

Insert Tables 4 and 5 about here

Two factors were extracted with eigenvalues greater than 1.0. Factor 1 was identified as integrated science process skills, since all five of the TIPS II subfactors loaded on it. Conversely, Factor 2 was identified as formal reasoning, since four of the GALT subfactors loaded on it. Interestingly, three of the subscales on the GALT also had substantial loadings on the integrated science process skills subfactor. The formal reasoning subfactor of controlling variables actually loaded higher on the integrated science process skills factor, while the formal reasoning subfactor of probabilistic reasoning and combinational reasoning had lower but still substantial loadings on the integrated science process skills factor. These results indicate overlap between integrated science process skills and formal reasoning with regard to controlling variables, probabilistic reasoning and combinational reasoning, which could account for the high correlation among total test scores for integrated science process skills and formal reasoning (Tobin and Capie, 1982; Dillashaw and Okey, 1980). All of the remaining subfactors loaded substantially on their respective factors and only negligibly on the opposite factor, providing evidence for their construct validity. Moreover, the designing an experiment subfactor appeared to be exclusively devoted to integrated science process skills, while the correlational reasoning subfactor appeared to be exclusively devoted to formal reasoning.

An interesting secondary finding of this study was the absence of any significant correlation between the number of science courses taken and integrated science process skills. Pearson r values for number of college science courses with TIPS II scores was -.07. Correlation of total (high school plus college) science courses (which ranged from 1 to 13, with an average of 4.6) was -.05. Neither relationship was significant.

Discussion

This study casts some doubt on the orthogonality of integrated science process skills and formal reasoning ability. For the TIPS II and GALT and the PSST and Lawson tests, the percent of shared variance was 27 and 38 respectively, indicating a moderate degree of overlap between integrated science process skills and formal reasoning ability. One implication of this finding is that researchers should be cautious in suggesting a cause and effect relationship between integrated science process skills and formal reasoning ability, since the two traits may to some extent represent the same construct. The construct of formal reasoning ability arose from the field of developmental psychology, whereas integrated science process skills had its origin in the science education literature. It is conceivable that the same or similar construct has been independently articulated by two different disciplines. This seems to be borne out in part by the similarity of test items commonly associated with each construct. For example, some of the GALT items intended to measure formal reasoning are suggestive of items in TIPS II intended to measure integrated science process skills, and vice versa. For the TIPS II and GALT this may have led to the high degree of overlap between them. Although a rigorous content analysis of these and other tests of formal reasoning and integrated science process skills is called for, it seems possible that measures of integrated science process skills may also measure formal reasoning by virtue of the fact that tests of integrated science process skills may require the subject to perform at least some integrative tasks that are commonly associated with formal reasoning. A content analysis might show that these integrative tasks are embedded mainly in the three factors, controlling variables, probabilistic reasoning and combinational reasoning, which were found to be common to both integrated science process skills and formal reasoning.

A further finding from this study was that scores on at least two of the tests examined, the TIPS II and GALT, may be susceptable to influence by the method of measurement they employ. One interpretation of the high correlation between scores on these two tests is that scores on both seemed to be uniformly influenced by the multiple choice format they used. Campbell and Fiske (1959) have referred to this type of influence as "method variance" and consider it a major cause of discriminant validity problems in tests of psychological abilit[illegible] the present study when integrated science process skills and formal [illegible]ing ability were measured using tests with different testing formats, the percent of shared variance between the measures decreased and the test data for formal reasoning ability met the standard for discriminant validity set forth by Campbell and Fiske.

While both formal reasoning ability and integrated science process skills remain important (and apparently manipulatable) variables for research, such importance may not be enhanced by implications of cause-effect relationships. At this time there is not strong evidence that the two traits originate separately. Until such evidence is found, researchers should be cautious in suggesting the independence of these traits. To imply that there is something manifestly important for researchers about correlations between these two traits may be similar to implying significance to the geometric fact that circles and ellipses, each with the same major diameter, have similar areas. The two shapes share common traits because they result from moving a point around a single axis. Although each geometric form is important, their common traits are hardly remarkable.

There seems to be no relationship between the number of science courses completed and integrated science process skills as measured by TIPS II for the sample population. This implies that science courses taken by subjects in this study do not enhance such skills. Perhaps content, rather than process is the nature of survey courses--the kind most likely to be taken by elementary education majors.

Future research should focus on effective means to enhance those reasoning skills considered essential for the processes of science. Skill definitions may need to be reconsidered in light of the findings cited above. Operational definitions for targeted subskills should be based on what can be reliably measured. But care must be taken to restrict implications of correlations among measured traits. The domain of human intelligence is often more complex than both our measuring instruments and labeling experience.

Table 1: Descriptions of the Four Tests

FORMAL REASONING:

Name:	Classroom Test of Formal Operations (Lawson)	Group Assessment of Logical Thinking (GALT)
Source:	Anton E. Lawson (1978)	Roadrangka, Yeany and Padilla (1983)
Number of Questions:	15	21
Question Type:	Video demonstration choice followed by written response.	3, 4, & 5 response multiple with pictoral format.
Scoring:	To be scored correct, items on both tests must have correct response PLUS a correct reason for that response.	

INTEGRATED SCIENCE PROCESS SKILLS:

Name:	Test of Integrated Process Skills (TIPS II)	Process Skills of Science Test (PSS)
Source:	Dillashaw and Okey (1980, revised in 1982)	Burns (1972)
Number of Questions:	36	48
Question Type:	4-response multiple choice	5-response multiple choice
Scoring:	Raw scores = number of correct responses.	

Table 2: Descriptive Statistics for the Four Tests (N=54)

Test	Number of Items	Mean Score	Standard Deviation	Lowest Score	Highest Score
T.I.P.S.	36	27.26	4.84	15	35
P.S.S.T.	48	21.81	5.92	10	34
G.A.L.T.	21	12.77	4.51	6	21
Lawson L.T.	15	10.71	2.82	4	15

Table 3: A Multitrait-Multitest Matrix (N=54)

	T.I.P.S. II (science process skills)	G.A.L.T. (formal reasoning)	P.S.S.T. (science process skills)	Lawson L.T. (formal reasoning)
T.I.P.S. II	(0.89)*			
G.A.L.T.	0.62	(0.85)*		
P.S.S.T.	0.62	0.50	(0.72)*	
Lawson L.T.	0.53	0.65	0.52	(0.68)*

* Alpha reliabilities from Padilla and Okey (1983), Roadrangka, Yeany and Padilla (1983), Burns (1972), and Lawson and Snitgen (1982) for the T.I.P.S. II, G.A.L.T., P.S.S.T., and Lawson L.T., respectively.

Table 4: Intercorrelations Among the TIPS and GALT Subscales

	Integrated Science Processing (TIPS)					Formal Reasoning (GALT)				
	1 Control & identify variables	2 Stating hypotheses	3 Operationally defining	4 Design an experiment	5 Graph and interpret data	6 Proportional reasoning	7 Controlling variables	8 Probabilistic reasoning	9 Correlational reasoning	10 Combinational reasoning
1	1.00	.68	.49	.54	.49	.42	.46	.39	.25	.40
2		1.00	.56	.52	.57	.48	.50	.46	.29	.41
3			1.00	.49	.54	.40	.46	.42	.25	.43
4				1.00	.47	.30	.39	.37	.14	.32
5					1.00	.42	.46	.55	.26	.43
6						1.00	.52	.55	.41	.42
7							1.00	.49	.25	.40
8								1.00	.31	.44
9									1.00	.27
10										1.00

Table 5: Factor Loadings for the TIPS and GALT Subscale *

Subscale		Factor 1	Factor 2
	1	.74	.23
	2	.73	.33
TIPS	3	.72	.26
	4	.81	.06
	5	.70	.32
	6	.33	.75
	7	.55	.47
GALT	8	.42	.62
	9	-.01	.79
	10	.44	.49

*Eigenvalues for Factors 1 and 2 were 4.85 and 1.05, accounting for 48.5 and 10.5 percent of the total variance, respectively.

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