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This paper describes the development of the Test of Science Processes, an instrument for assessing achievement and diagnosing weaknesses in the use of science processes by students in grades 7, 8, and 9. The science processes considered were observing, comparing, classifying, quantifying, measuring, experimenting, inferring, and predicting. The test consists of 96 multiple-choice questions and requires an actual testing time of 73 minutes. Scoring of the instrument yields a total score and eight sub-scores, one for each process. The test was initially administered to 3,673 students in the state of New York representing all ranges of ability and socio-economic background. Norms are reported by grade, sex, urban versus suburban and for the total sample within each grade. There is evidence of both content and curricular validity of the test. There is also evidence for criterion related validity, but more conclusive evidence is needed. The predictive validity of the test has yet to be studied. (BC)

THE DEVELOPMENT OF THE TEST OF SCIENCE PROCESSES[1]

Presented at the meetings of the National Association for Research in Science Teaching, Passadena, California, February 8, 1969

by

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[1]This work was performed while the author was associated with the Computer Center at Teachers College, Columbia University.

SUMMARY

In this study, an instrument to assess achievement and diagnose weaknesses in the use of science processes by students in grades seven, eight, and nine was developed. It is entitled Test of Science Processes. The science processes considered were: Observing, Comparing, Classifying, Quantifying, Measuring, Experimenting, Inferring, and Predicting. These were arrived at after a study of relevent texts and other literature. The original list was edited and condensed and the behaviors which students must exhibit in order to demonstrate competence in the use of each of the processes were specified in detail. This statement of behaviors was submitted to experts for their opinions and validation before final writing. The final version of the statement of behaviors served as the blueprint for the Test of Science Processes.

The instrument has the following characteristics: 1. it consists of ninety-six multiple choice (five choice) questions; 2. it requires total actual testing time of seventy-three minutes (some students may finish in less); 3. the test booklet is printed with black and white illustrations and, for the twelve questions which require color, 35 mm color slides are used; 4. scoring of the instrument yields a total score (Kuder-Richardson formula 20 reliability = .91) and eight subscores, one for each process (reliabilities from about .30 to about .80).

The instrument was administered to 3,673 students from schools in the Bronx, New York, and Rockland County, New York. This sample was carefully selected to include all ability levels and a wide range of socio-economic backgrounds. The results of this administration were used to create norms for total score and for each of the eight subscores. The norms are reported by grade, by sex, and by urban verses suburban, and for the total sample within each grade. The results were

also employed in a study of the uniqueness of each of the subscores (i.e., the proportion of the non-error variance which is unique to that subscore.) Six of the subscores were found to have uniquenesses between .1244 and .1578. The other two subscores had uniquenesses which are not significantly different from zero but this may be attributable to their short lengths. The item analysis data for all ninety-six questions administered to these students are available.

There is considerable evidence of both the content and the curricular validity of the test. The criterion-related validity of the test is very difficult to assess because this is the first attempt to measure this age level students' ability to use science processes, A small investigation was undertaken to demonstrate the criterion-related validity (where the criterion is teacher rating of the students' abilities to use the processes.) The results of this investigation were not unequivical. However, they do give some indication of a degree of criterion-related validity. More conclusive evidence of this must await much more extensive investigations. The predictive validity of the Test of Science Processes has not yet been studied.

ACCOUNT OF CONSTRUCTION

It was decided that the test would concentrate exclusively on assessing students' ability to use science processes. This approach proved to have advantages. It allowed for the production of a test which draws its examples from several of the natural sciences and which is shorter that is normally necessary for assessing "achievement in science" based on traditional subject demarcations. For this reason, it is thought that different methods of teaching may affect students' performances on the test, but different subject matter emphases should not. This remains to be investigated.

The first major step to be undertaken was the definition of and statement in behavioral terms of those science processes which it was appropriate to expect seventh, eighth, and ninth graders to be able to use in the light of current science education. This statement was meant to serve, in its final form, as the blueprint for the Test of Science Processes.

Many elementary and junior high school science texts and research reports were carefully studied and summarized to determine the processes of science which seventh, eighth, and ninth graders are currently expected to be able to use. The resulting list of processes was then carefully reorganized, condensed, stated in behavioral terms, and edited into a more polished statement which was ready for validation. The behaviors on the list were categorized under eight processes: Observing, Comparing, Classifying, Quantifying, Measuring, Experimenting, Inferring, and Predicting.

Evidence of the curricular validity of the statement of science processes was gathered by submitting it to experts in science education. The statement was mailed to about thirty prominent science educators (these are listed in Appendix A of this report along with the requirements for inclusion on this list and the instructions for responding to the statement.)

Twenty-two usable responses were returned and, on the basis of these, the final statement of processes was written. It was decided arbitrarily that the following rules would be adhered to in writing the final statement:

1. No new behaviors would be added to the final statement of processes.
2. No behavior would be included in the final statement of

processes which more than one-third of the respondents decided was inappropriate with regard to difficulty (either too hard or too easy.)

3. No behavior with a mean of less than 2.5 on the three-point "appropriateness in the light of current science education" scale would be included in the final statement of processes.

4. All behaviors listed in the statement submitted for validation which passed rules two and three, above, would be included verbatim in the final statement of processes unless their mean scores on the three-point "clarity" scale were below 2.5, in which case they would be given minor rewriting in accordance with the suggestions of the respondents before inclusion.

Only one behavior was rejected as too difficult and only three were considered inappropriate in the light of current science education. Six of the remaining fifty-three behaviors were rewritten in accordance with the suggestions of the respondents because their mean scores on the "clarity" scale were less than 2.5. (None of these six had a mean of less than 2.33.)

The final statement of processes which was produced and used as the blueprint for the Test of Science Processes thus consists of fifty-three behaviors categorized under eight major processes of science. Of these, forty-seven were validated verbatim by the science education experts and six were validated with minor rewriting suggested.

On the basis of the blueprint, Form I of the Test of Science Processes was written. Form I consisted of ninety-eight multiple-choice items. Each item consisted of a 35 mm color slide visual stimulus, a mimeographed stem, and five choices. Form I was designed to be used with simultaneous vocal stimulus, also. The voice gave instructions and read the questions to minimize reading problems.

Form I was administered to 156 seventh, eighth, and ninth graders from a Bronx, New York, public intermediate school in January, 1968. The results of this administration were carefully item analyzed and, on the basis of the analysis, Form II of the Test of Science Processes was written.

Three items were dropped from Form I and one new item was added so that Form II consisted of ninety-six multiple choice items. Many of the other questions from Form I were given at least some rewriting prior to inclusion in Form II on the basis of the item analysis and the suggestions of Dr. Willard J. Jacobson and Dr. Robert L. Thorndike, of Teachers College, Columbia University.

The ninety-six items and printed instructions were typewritten (with right-hand justified margins) and the color slides (except those for questions one through twelve on Form II) were converted to tables or black and white prints. The correct answers to the items were randomized using a table of random numbers and the questions were arranged in a "saw-toothed" order of increasing difficulty within each subscore (based on the difficulty of the item when included on Form I). The entire test was then "cut and pasted" into "camera-ready" copy to be photo offset and commercially printed.

After Form II was printed, it was administered in February, 1968, to 3,673 seventh, eighth, and ninth graders from Rockland County, New York, and the Bronx, New York. The results of these administrations were used to determine the norms, item statistics, reliabilities, and validities.

Following the administration of Form II, the statistical analyses were performed using the facilities of the Teachers College Computer

Center. The final step in the construction of the Test of Science Processes was the writing of a very complete manual and the inclusion in it of the statistical tables.

The procedures for construction of this type of test are frequently enumerated (if less frequently employed) and I shall assume that this audience is well acquainted with them. Therefore, I shall devote the rest of this paper to those aspects of the Test of Science Processes and its development which are somewhat unique.

BLUEPRINT

Prior to the actual construction of items and the arrangement of them into a test, a blueprint must be created which will provide guidelines for the preparation and contents of the final instrument. Traditionally, blueprints are two dimensional with content areas specified along one axis and the behaviors to be performed specified on the other axis. At each intersection of behavior and content area, the number of items (or, sometimes, the percent of the total test) which will deal with using that behavior on that content is specified.

The blueprint for the Test of Science Processes is essentially one dimensional. In this sense, it is rather untraditional. It was decided very early in the construction of the test that it would be concerned strictly with assessing students' abilities to use science processes regardless of particular science content. Therefore, one dimension is simply "science." It was the other dimension - the science processes - which had to be carefully and specifically defined in behavioral terms.

The definition of those science processes to be included involved several stages. The first stage was a detailed survey of the relevant literature. This included a careful investigation of major statements of the psychology of science learning and of the philosophy of science and science education. In addition to theoretical sources, numerous science tests, texts, and syllabi were consulted. All of the literature which was surveyed is listed in Appendix B of this paper.

There are clear parallels between the AAAS list of processes and the blueprint of the Test of Science Processes. Indeed, perhaps the greatest single debt is owed to this one source even though, as with all the other research and literature reviewed, it is not specifically directed at seventh, eighth, and ninth graders. And, while it is very similar to and was very helpful in creating the blueprint, many other sources were also consulted in order to produce a valid and workable blueprint.

In summarizing the extensive review which was done of the literature relative to defining science processes which students of this age group should be able to use, it may be said that while much work has been done on similar problems and closely related topics, there is nothing specifically defining processes of science which it is appropriate to expect seventh, eighth, and ninth graders to be able to use. Therefore, the task remained to refine what had been done before, combine it with what is currently expected of students in these grades as evidenced by current tests, texts, syllabi, etc., and synthesize and validate a blueprint. The final result of this undertaking - the blueprint of the Test of Science Processes - is included as Appendix C of this paper.

SAMPLE TEST ITEMS

All of the items on the Test of Science Processes are five choice, multiple choice items. Each was written specifically to test one of the abilities detailed in the blueprint. To give a brief sample of the test, several items are included in Appendix D of this paper.

RELIABILITY

The following table presents reliability data for the Test of Science Processes, Form II. The reliabilities reported are the results of internal analyses (using the Kuder-Richardson Formula 20) based on a single administration of the test. Correlations between alternate forms of the test and test-retest correlations have not been obtained.

The sample is the same as that used for norming the test. It was drawn from public junior high schools in Rockland County, New York, and in the Bronx, New York.

Although the test is timed during administration, this probably had a negligable effect on the performances of the students because: (1) the time limits were liberal enough to allow most (over 84%) of the students to finish, (2) all students were forced to attempt all parts of the test, and (3) if they finished early, students were allowed to go back and work on any question(s) which they skipped either because of difficulty or time limitations in a particular section.

TABLE I	SUBURBAN -- GRADE			URBAN -- GRADE			TOTAL -- GRADE		
RELIABILITIES	7	8	9	7	8	9	7	8	9
TOTAL SCORE 96 ITEMS	.91	.91	.91	.90	.91	.90	.91	.91	.90
I OBSERVING 9 ITEMS	.47	.41	.47	.41	.42	.41	.41	.42	.42
II COMPARING 5 ITEMS	.34	.35	.26	.37	.31	.31	.37	.31	.30
III CLASSIFYING 13 ITEMS	.71	.67	.62	.62	.58	.60	.64	.60	.60
IV QUANTIFYING 12 ITEMS	.74	.75	.69	.69	.67	.64	.69	.68	.65
V MEASURING 25 ITEMS	.79	.79	.82	.71	.80	.77	.72	.80	.78
VI EXPERIMENTING 10 ITEMS	.54	.54	.57	.43	.47	.46	.45	.49	.48
VII INFERRING 14 ITEMS	.53	.48	.59	.60	.63	.57	.59	.62	.57
VIII PREDICTING 8 ITEMS	.32	.42	.51	.49	.56	.48	.48	.55	.48

VALIDITY

The validity of an instrument such as the Test of Science Processes is a crucial question. There is considerable evidence of both the content and the curricular validity of the test, due to the care employed in the construction and validation of the blueprint and items. The technique employed is often referred to as "validation by experts."

The predictive validity of the Test of Science Processes has not yet been investigated because there has not yet been time enough since the creation of the test to follow students through junior and senior high school and correlate high school achievement with results of the test. At least until these data can be gathered (and even thereafter) it is urged that the results of the Test of Science Processes be used as only one of several sources of information employed by professional guidance personnel to help students plan courses of study and remediation.

The criterion-related validity of the Test of Science Processes is extremely difficult to investigate because this is the first attempt to assess this age level students' ability to use science processes. Although it may seem slightly irreverent to make the comparison, the problem is somewhat akin to the problems involved in validating the first IQ test at the beginning of this century.

In an attempt to provide at least some evidence of criterion-related validity, a small investigation was undertaken. A group of students (N = 35) took the Test of Science Processes and their teacher, who had observed their classroom and laboratory behavior for more than a full semester, rated them individually on a scale of zero to nine on each of the eight processes. The teacher was given a copy of the blueprint and carefully instructed to rate each of his students on his or her ability to use the processes as defined therein. In an attempt to minimize "halo effect" and increase the reliability of the teacher's ratings, the teacher rated each student on the first process and then shuffled the papers so as to rate the students in a different sequence on the next process and so on through the eight processes. The students' eight raw subscores on the test were correlated with their teacher's eight ratings. The students' total raw scores were correlated with the sum of the teacher's eight ratings. High correlations in the principal diagonal of the resulting nine by nine correlation matrix would be evidence of validity related to the criterion of teacher rating of ability to use the processes.

Clearly there are weaknesses in this investigation (e.g., small sample, possible teacher biases, untested nature of the rating system). However, in view of the unique nature of the Test of Science Processes, this was considered a small price to pay for an indicator of validity in the absence of other more traditional techniques.

The results of the correlation analysis are given in Table II on the following page.

In Table II, the correlations of particular interest are those along the principal diagonal (they are heavily underlined). These are the correlations between the teacher's ratings and the students' subscores and total scores. The three bottom rows contain the rank of the correlation in the principal diagonal relative to the other correlations in that column (these could range from one to nine), the average of all of the correlations except those in the principal diagonal in each column, and the difference between the correlation in the diagonal and the average correlation in each column.

As evidence of the criterion-related validity of the Test of

TABLE II CORRELATIONS, MEANS, AND STANDARD DEVIATIONS FOR VALIDATION EXPERIMENT

			I	II	III	IV	V	VI	VII	VIII	TOTAL SCORE
			SUBSCORES ON THE TEST OF SCIENCE PROCESSES								
		MEAN	5.57	4.17	9.74	9.97	15.77	5.26	7.06	4.71	62.26
		S.D.	1.48	.99	2.33	1.52	4.72	2.05	2.84	1.53	12.99
TEACHER RATINGS	MEAN	S.D.	CORRELATIONS								
OBSRVNG	5.46	2.45	.277	.088	-.042	.169	.327	.339	.385	.272	.328
COMPRNG	5.00	2.00	.089	.115	-.086	.135	.246	.301	.316	.164	.236
CLSFYNG	5.37	2.21	.122	.091	.198	.221	.409	.335	.414	.329	.394
QNTFYNG	4.94	2.81	.313	.132	.149	* .372	.454	.377	.438	.417	.486
MESURNG	5.40	2.21	.215	.089	.010	.291	** .464	.295	.334	.244	.348
EXPRMNT	4.14	2.89	.358	.125	.225	.408	.460	* .356	.476	.316	.503
INFERNG	4.91	2.32	.109	-.032	.053	.257	.353	.209	* .373	.151	.299
PRDCTNG	4.60	2.50	.294	.041	.155	.460	.558	.342	.310	* .349	.470
TOTAL	40.11	17.52	.248	.057	.067	.331	.452	.370	.425	.327	** .477
RANK OF DIAG CORR (1-9)			4	3	2	3	2	3	6	2	3
AVG OF CORRS OTHER THAN THOSE IN THE DIAGONAL			.219	.074	.066	.284	.407	.321	.387	.278	.383
$r_{diag} - r_{avg}$			+.058	+.031	+.132	+.088	+.057	+.035	-.014	+.071	+.094

* $P < .05$ that H_o: $r = 0$ is true; ** $P < .01$ that H_o: $r = 0$ is true. N = 35

Science Processes, the following should be noted: 1. in all but one case, the correlation of the teacher's rating with the students' subscores was higher than the median correlation in that column (rank of four or better); 2. in all but one case, the correlation in the principal diagonal was higher than the average of all the other correlations in that column; 3. in all but two cases, the correlations in the principal diagonal ranked second or third in their columns, once fourth and once sixth; and 4. all of the correlations in the principal diagonal are positive and six of them are significantly different than zero, two of these with probability less than .01.

Clearly, this evidence is not unequivical. One should not expect it to be so in view of the low reliabilities of the short subscores and the imperfections of the experiment (small N, teacher bias, etc.). However, it may be interpreted as at least some indication of a degree of criterion-related validity where the criterion is teacher rating of the students' ability to use the processes.

Several other much more extensive experiments of this and similar natures are contemplated to further investigate the criterion-related validity of the Test of Science Processes. Investigations of some of the correlates of success on the test are also under consideration. As these are completed, they will be reported.

CORRELATIONS

For the use of researchers and others who may be interested, the product-moment correlations of the total score and the eight subscores for the entire norming sample are presented below. Since it may be desirable to study data for only a particular subgroup of the population, the raw data for calculating other sets of correlation coefficients is available from the author in punched card form. When referring to these correlations, users are cautioned (1) to consult the corresponding reliabilities since these dictate the theoretical maximum meaningful correlations and (2) to keep in mind that the correlations between subscores and the total score are artificially raised by inclusion of the subscore within the total score.

TABLE III CORRELATION MATRIX

	PROCESSES (subscores)							
	I	II	III	IV	V	VI	VII	VIII
TOTAL SCORE	.666	.586	.758	.786	.883	.685	.740	.665
I OBSERVING	1.000	.397	.484	.481	.524	.379	.405	.346
II COMPARING		1.000	.489	.471	.425	.353	.341	.310
III CLASSIFYING			1.000	.584	.587	.437	.452	.389
IV QUANTIFYING				1.000	.652	.438	.461	.441
V MEASURING					1.000	.536	.564	.511
VI EXPERIMENTING						1.000	.497	.423
VII INFERRING							1.000	.557
VIII PREDICTING								1.000

UNIQUENESS

In a test such as the Test of Science Processes that contains subscores which are unique in a logical and a curricular sense, the question must be asked if they are also unique in an empirical sense. The first investigation of this question which was undertaken was a principal components factor analysis of the matrix of intercorrelations of the subscores. This analysis is summarized in Table IV.

The analysis was first performed with unity in the principal diagonal and the result was one gereral factor, about evenly weighted on all eight subscores, which accounted for better than fifty percent or the variance. A second factor was found which accounted for about ten percent of the variance. No other factors accounted for as much as eight percent of the variance.

By rotating the first two factors, it was possible to force them to appear to be a first-half-of-the-test factor and a second-half-of-the-test factor. But this was not very obvious and a much more defensible interpretation would be one general factor (perhaps "inteltigence") and no other significant factors.

This later interpretation was further supported by a second principal components factor analysis which was performed after substituting the squared multiple correlations (as an approximation for the communalities) in the principal diagonal of the matrix. This analysis also yielded one general factor which accounted for about forty-six percent of the variance and no other factors which accounted for as much as four percent of the variance.

TABLE IV PRINCIPAL COMPONENTS FACTOR ANALYSIS WITH UNITY IN THE PRINCIPAL DIAGONAL

	FACTORS							
SUB-SCORES	1	2	3	4	5	6	7	8
1	.6854	.2575	.5215	.0283	.4279	.0603	.0354	.0546
2	.6371	.4695	-.5293	.0523	.2755	.0414	-.0940	-.0642
3	.7644	.2741	.0073	.0065	-.2547	-.3433	.3961	.0245
4	.7864	.1795	.0566	.1148	-.3717	.2262	-.2321	.2993
5	.8359	-.0373	.1466	-.0160	-.2105	.0803	-.1468	-.4535
6	.6942	-.2454	-.1009	-.6407	.0493	.1401	.0926	.0793
7	.7353	-.4066	-.0386	.0692	.1277	-.4246	-.2884	.0884
8	.6775	-.4807	-.1393	.3825	.0973	.2428	.2744	.0122
EIGEN VALUE	4.2593	.8523	.6080	.5787	.5347	.4398	.4095	.3173
PERCENT TRACE	53.242	10.653	7.600	7.234	6.682	5.497	5.119	3.966

TABLE IV CONTINUED — VARIMAX ROTATION OF THE FIRST TWO FACTORS

SUB-SCORES	FACTORS 1	2
1	.6753	-.2830
2	.7856	-.0957
3	.7441	-.3252
4	.6952	-.4090
5	.5823	-.6008
6	.3366	-.6549
7	.2557	-.8003
8	.1629	-.8147

PRINCIPAL COMPONENTS FACTOR ANALYSIS
WITH SQUARED MULTIPLE CORRELATIONS
IN THE PRINCIPAL DIAGONAL

SUB-SCORES	FACTORS 1	2	3	4	5	6	7	8
1	.6238	.1212	.0546	.0682	.0601	.0757	.1761	.0786
2	.5730	.1953	-.0893	-.1553	.1238	.0696	-.0246	-.0404
3	.7186	.1839	.0943	.0230	-.2498	.0872	-.0254	-.0119
4	.7481	.1431	-.0342	.2024	.0924	.0908	-.0467	-.0751
5	.8100	-.0152	-.0569	-.2353	-.0169	.0983	-.0211	.0424
6	.6341	-.1262	.0928	.0875	.0678	.0770	-.1266	.1062
7	.6870	-.2571	-.2625	.0762	-.0724	.0834	.0401	-.0123
8	.6213	-.2541	.2294	-.0625	.0358	.0754	.0438	-.0874
EIGEN VALUE	3.7102	.2540	.1544	.1431	.1013	.0547	.0544	.0345
PERCENT TRACE	46.378	3.175	1.931	1.788	1.266	.684	.681	.431

TABLE IV VARIMAX ROTATION OF THE FIRST TWO FACTORS
CONTINUED

	FACTORS	
SUB-SCORES	1	2
1	.5413	-.3329
2	.5541	-.2440
3	.6535	-.3509
4	.6476	-.4009
5	.5860	-.5594
6	.3814	-.5221
7	.3317	-.6542
8	.2854	-.6075

It would seem that the most reasonable conclusion to be drawn from the factor analysis is that there is one large general factor (probably "intelligence") which accounts for about half of the non-error variance and that there are probably no other major factors which involve more than one of the subscores. This leaves about fifty percent of the non-error variance to be accounted for by the individual subscores.

An analysis of the unique contribution of each subscore to the non-error variance was undertaken. The total variance of a particular subscore may be thought of as being composed of a portion which is common with and may be accounted for by the rest of the test (this portion may be approximated by the squared multiple correlation of all the other subscores with the one subscore in question and symbolized by r^2_{iK}) and a portion which is unique to the particular subscore (symbolized by S^2_{Ui}).

Since both of these portions are normally expressed as decimal proportions of the total variance, they must sum to unity.

That is: $1 = r^2_{iK} + S^2_{Ui}$

or: $S^2_{Ui} = 1 - r^2_{iK}$

This is the equation for the uncorrected unique variance. A correction for attenuation due to error or unreliability must be applied to obtain the corrected unique proportion of the non-error variance (symbolized by ${}_cS^2_{Ui}$). The correction involves division of the squared multiple correlation by the product of the reliability of the subscore in question (r_{iI}) and the reliability of the rest of the test (r_{kK}). The formula is: ${}_cS^2_{Ui} = 1 - \dfrac{r^2_{iK}}{r_{iI} \times r_{kK}}$.

This analysis was performed on each of the eight subscores of the Test of Science Processes and the results are presented in the table below.

TABLE V UNIQUENESSES

SUB-SCORE	r_{iK}	r^2_{iK}	r_{iI}*	r_{kK}*	$r_{iI}r_{kK}$	$\frac{r^2_{iK}}{r_{iI}r_{kK}}$	${}_cS^2_{Ui}$
I	.5962	.3554	.42	.91	.3822	.9299	.0701
II	.5612	.3150	.33	.91	.3003	1.0490	-.0490
III	.6910	.4774	.61	.90	.4490	.8696	.1304
IV	.7215	.5206	.67	.90	.6030	.8633	.1367
V	.7703	.5933	.77	.88	.6776	.8756	.1244
VI	.6079	.3696	.47	.91	.4277	.8642	.1358
VII	.6753	.4561	.59	.90	.5310	.8589	.1411
VIII	.6190	.3832	.50	.91	.4550	.8422	.1578

* reliabilities calculated using Kuder-Richardson formula 20

The last column on the right in Table V contains the unique proportion of the non-error variance contributed by each of the eight subscores. (The "-.0490" reported for subscore II is probably a random variation from a true value of approximately zero, since a negative uniqueness is meaningless.) It should be noted that the uniqueness is the proportion of the non-error variance (expressed by the reliability, r_{iI}). So, for example, in subscore VIII, about 15 3/4 percent of the 50 percent non-error variance is unique to that subscore.

Several interpretations could be offered for the results of this analysis, but it would probably be best to wait for a more controlled investigation (perhaps with cross-validated reliabilities and alternate forms of the test). For the present, it should be sufficient to say that the last six subscores appear to have at least a certain degree of uniqueness and subscores I and II may not be very unique because their short lengths and low reliabilities may preclude such a possibility.

The statistics of this uniqueness analysis are discussed in detail by Davis.[1] It might be noted that Davis considered uniquenesses of more than .12 to be quite good.

COMPUTER PROGRAMS

During the course of this study, several computer programs have been written and adapted for statistical processing of the data needed for test development. These include an item analysis program and programs for scoring, subscoring, reliability, validity, and norming.

These programs incorporate several new, unique, and efficient features and are now available for use in the development and evalution of other new test materials. Among these features are:

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[1]Frederick B. Davis, Identification and Measurement of Reading Skills of High-School Students (Washington, D.C.; Office of Education, United States Department of Health, Education, and Welfare, Cooperative Research Project no. 3023, 1967).

A. In the item analysis program, the option to call for any combination of the following: frequency of responses to each choice (including "omits" and "didn't reaches"), percent of responses, point biserial correlations of each choice with total score, and biserial correlations of each choice with total score. Also, the user has the option of concurrent scoring of each test paper during the analysis.

B. In the scoring and subscoring program, the user receives Kuder-Richardson formula 20 reliabilities for each subscore (up to a maximum of ten) as well as for the total score and group means, standard deviations, and ninety-five percent confidence intervals for the means of each subscore as well as for the total score. Furthermore, the subscores may be overlapping (i.e., items may be included in two or more subscores simultaneously.)

C. The correlation program used in norming and validating allows for from two to seventy-five variables to be correlated at one time all within the 60K core storage of an IBM 1620 model II computer. It is so flexible that only one format card needs to be changed for any one run even though the number of variables changes. It also allows the user to obtain the regression equations for all or some of the variables merely by setting the console switches.

EDUCATIONAL SIGNIFICANCE OF THE STUDY

1. Need: Current trends in science education have created a need for instruments with which to measure students' progress toward newly defined objectives. Until the completion of the Test of Science Processes, no instrument was available with which to measure seventh, eighth, and ninth grade students' ability to use science

processes. This study was an attempt to fill this need. The instrument is intended for making measurements of progress toward behavioral objectives which stress science processes. It should enable educators to prepare more reliable and valid evaluations of their students' achievement in these areas which are now being emphasized.

2. Extent of Applicability: In view of the basic nature of the processes being tested and the non-specific nature of the content material employed, this instrument should be applicable for use with almost all students in grades seven, eight, and nine throughout the country. As Jacobson has so eloquently stated: "Science programs must do much more than prepare young people for science research; every young American, regardless of his future calling, has a right to an education in science that will be of interest and value."[1] In order to make the instrument available to the largest number of students (and more valid at the same time) an attempt has been made to minimize the reading difficulty of the items, but never at the expense of clarity or scientific accuracy. Questions include mathematics because science is mathematical; however, the computations have been kept as simple as possible so that the students who are weak in mathematics are not unduly penalized.

3. Diagnosis: Because of the specific, item-by-item analysis provided in the test manual, and the subscoring routines and norms, the Test of Science Processes makes possible much more specific analyses of the weaknesses of curricula than was previously possible. Also, it

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[1]Willard J. Jacobson, "Science Curriculum Change in the United States since 1957," a draft of a chapter from the forthcoming book, Strategies for Curriculum Change, edited by R. Murray Thomas, Lester B. Sands, and Dale L. Brubaker (mimeographed, 1967) p. 21.

may now be possible to prescribe remedial work for students and place them more efficiently in their future courses - this remains to be investigated and can only be regarded as tentative in the light of the low reliabilites of some of the subscores.

There is an alarmingly high drop-out rate in high school science courses. It has been reported that about seventy-seven percent of all junior high school students are enrolled in some science course.[1] When these students reach high school, they are usually required to take biology, and it is reported that eighty-six percent of the students in the grade in which biology is offered are enrolled in a biology course.[2] By the time these students reach the grade in which chemistry is offered, only thirty-eight percent of them are enrolled in the course.[3] And, by the time they reach the grade in which physics is offered, only twenty-three percent of them are enrolled in the physics course.[4]

One possible explanation for at least part of this tremendous drop-out rate in science is that students have specific weaknesses in various areas required in high school science courses and because of these they have failed to enroll in or have dropped out of science courses. If the Test of Science Processes makes possible a better

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[1]Lola Ericksen Rogers, Science Teaching in the Public Junior High School (Washington, D.C.; United States Government Printing Office, 1967) (Catalogue number 5.5229:29067) p. 8.

[2]Kenneth A. Simon and W. Vance Grant, Digest of Educational Statistics 1966 (Washington, D.C.; United States Government Printing Office, 1966) (Catalogue number 5.210:10024-66) p. 34.

[3]Ibid.

[4]Ibid.

diagnosis of some of these weaknesses, then, perhaps, remedial work, assigned on the basis of the diagnosis, may contribute to a decrease in the science drop-out rate.

4. Use in Educational Research: Because of the unique nature of the test and its very complete manual, the Test of Science Processes should be a valuable tool for educational researchers. For example, using the test, the differences in students resulting from various types of teaching could be studied. Or, other instruments of a similar nature could be developed and validated. Or, any of numerous other research projects could be undertaken which investigate "objectively" areas previously measurable only in terms of observations or subjective reports. In fact, the very existence of an instrument of this nature (i.e., objective testing of process-related behavioral objectives) demonstrates to science educators the feasibility of the development of other such instruments and of objective studies in this area.

APPENDIX A

LIST OF SCIENCE EDUCATION EXPERTS TO WHOM THE STATEMENT OF SCIENCE PROCESSES WAS SENT FOR VALIDATION AND COMMENT

1. J. Myron Atkin
2. Darrell Barnard
3. Glenn Blough
4. David Butts
5. Albert Carr
6. Robert Karplus
7. Paul Rosenbloom
8. Herbert Schwartz
9. Harold Spielman
10. Herbert Thier
11. Jay W. Erickson
12. Henry Walbesser
13. Harry V. Scott
14. Fletcher Watson
15. Matthew Bruce
16. Vernon Rockcastle
17. Leopold Klopfer
18. George Pallrand
19. Archie Lacey
20. Gladys Kleinman
21. Steven Winter
22. Charles Walcott
23. John Read
24. Paul Hurd
25. Robert Gagne
26. Ernest Burkman
27. W. C. Van Deventer
28. Frederick Ferris
29. Uri Haber-shaim
30. Charles Heimler
31. John H. Woodburn

The inclusion of a science educator on this list does not in any way imply his agreement with or endorsement of the Test of Science Processes or its blueprint. As is indicated in the text, not all of these people returned the statement which was sent to them and it is impossible to determine which ones returned it because they were not necessarily signed.

In order to be included on the list of people to whom the statement of science processes was mailed, a person had to meet requirements one and two below and either three or four or both three and four.

Requirements:

MUST HAVE:

1. Has taught children at elementary and/or junior high school level and/or prepared teachers to teach at either one or both of these levels.

2. Has been recommended by at least one member of professorial rank of the Department of Science Education of Teachers College, Columbia University as being knowledgeable regarding developments in elementary and junior high school science education.

EITHER OR BOTH:

3. Has published or done research on science for the junior high school.

4. Has worked with a recent national science curriculum project (since 1960.)

The respondents were given the following instructions: "For each of the behaviors listed under the eight processes, please circle the appropriate number under each category. The definition of the categories is given below. Please feel free to make any written comments wherever you feel they are needed.

CLARITY:

1 - UNCLEAR - needs major rewriting.

2 - CLEAR, but the minor changes indicated would be very clarifying.

3 - CLEAR AS WRITTEN - no changes needed.

APPROPRIATENESS IN THE LIGHT OF CURRENT SCIENCE EDUCATION:

1 - INAPPROPRIATE - not worth including.

2 - APPROPRIATE, but not of the utmost importance.

3 - CRUCIAL - must be included.

DIFFICULTY WITH REGARD TO THIS AGE LEVEL:

1 - VERY EASY for 11- to 14-year-old students -- trivial when asked of this age student.

2 - TOO DIFFICULT for most 11- to 14-year-old students -- do not include.

3 - APPROPRIATE to expect students at this age level to know or to be learning."

APPENDIX B

BIBLIOGRAPHY

This appendix consists of a bibliography of those materials to which reference was made during the construction of the Test of Science Processes and its manual. Those entries which are marked with a "*" are general references which were not consulted during the preliminary research for and construction of the blueprint. All of the other entries were consulted at least once during either the preliminary research for or construction of the blueprint and may have been referred to at other times, also.

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APPENDIX C

BLUEPRINT OF THE TEST OF SCIENCE PROCESSES

Process I OBSERVING

In order for a student to demonstrate competence in using the process of observing, he should be able to do the following:

Behaviors	Questions[1]
1. Demonstrate an operational knowledge[2] of the physical properties of objects.	14, 19
2. Identify and describe the objects which interact in a system.	13, 18
3. Identify and describe the results of interactions of objects and systems of objects in terms of initial and final states.	17
4. Distinguish among various spatial relationships of the objects within a given system.	15, 20
5. List the observable characteristics of a given phenomenon.	16, 21

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[1] The numbers under this heading are the numbers of the questions on Form II of the Test of Science Processes which are intended to assess the students' ability to perform the specified behavior.

[2] The terms and phrases used in the blueprint which do not have precise behavioral or scientific meanings, or whose common meanings are either imprecise or somewhat different from their usage in the blueprint, are defined in the "Glossary" which follows Process VIII, Predicting.

Process II COMPARING

In order for a student to demonstrate competence in using the process of comparing, he should be able to do the following:

Behaviors	Questions
1. Describe, in terms of their physical properties the similarities of two or more of each of the following:	3, 23, 24
a. Objects	
b. Systems of objects	
c. Interactions of objects and of systems of objects	
d. Relative positions of objects	
2. Contrast, on the basis of differences in their physical properties, two or more of each of the following:	7, 22
a. Objects	
b. Systems of objects	
c. Interactions of objects and of systems of objects	
d. Relative positions of objects	

Process III CLASSIFYING

In order for a student to demonstrate competence in using the process of classifying, he should be able to do the following:

Behaviors	Questions
1. Group objects or systems of objects according to a given property.	9, 10, 26

Process III CLASSIFYING (cont.) — **Questions**

	Behaviors	Questions
2.	Select and justify an appropriate property and group objects or systems of objects according to that property.	1, 27
3.	Group objects or systems of objects according to two simultaneous properties.	4, 5
4.	Select and justify two or more appropriate simultaneous properties and group objects or systems of objects according to these properties.	28, 29
5.	Given a group of objects, identify the property or properties on which they are grouped.	25, 11
6.	Given a set of objects or systems of objects, remove a specified number of members from the original set to form two new sets which are grouped on the basis of one or more given simultaneous properties.	6, 2

Process IV QUANTIFYING

In order for a student to demonstrate competence in using the process of quantifying, he should be able to do the following:

	Behaviors	Questions
1.	Demonstrate an operational knowledge of ordinal and cardinal numbers up to one million and of negative numbers.	30, 32, 36
2.	Demonstrate an operational knowledge of simple fractions, percents, and decimals.	33, 35, 37

Process IV QUANTIFYING (cont.)	Questions
3. Be able to order a group of objects or systems of objects from most to least (or vice-versa) on one or more simultaneous orderable properties.	31, 34
4. Be able to arrange and to read data in various graphic and tabular formats.	38, 39 40, 41

Process V MEASURING

In order for a student to demonstrate competence in using the process of measuring, he should be able to do the following:

Behaviors	Questions
1. Suggest and use "home-made" units for measuring the properties of objects.	51, 53
2. Demonstrate an operational knowledge of units of measure, the function of widely accepted units, the names and approximate sizes of the most common units such as inch, foot, centimeter, meter, pound, quart, gram, kilogram, liter, second, degree Celsius, etc.	52, 54 62, 65 66
3. Be able to select the appropriate units for making a particular measurement.	46, 60
4. Be able to <u>estimate</u> the dimensions and properties of an object (including temperature, size, mass, etc.) for purposes of ordering, describing, and classifying.	47, 50
5. Be able to <u>measure</u> the dimensions and properties of an object (including temperature, size, mass, etc.) for purposes of ordering, describing, and classifying.	45, 55

Process V MEASURING (cont.) **Questions**

6. Demonstrate an operational knowledge of area and volume in terms of one-, two-, and three-dimensional measurements (e.g., $a=l^2$ and $a=l \times w$; $v=l^3$; $v=h \times a=h \times l^2$; and $v=h \times l \times w$.) — 56, 57
7. Be able to measure time. — 44, 58
8. Be able to measure the rate of change of a property of an object or a system of objects. — 48, 59
9. Represent and recognize an object or a system of objects by a scale diagram. — 49, 61
10. Represent and recognize the spatial relationships among two or more objects by a scale diagram (mapping.) — 63, 64
11. Recognize the appropriateness and limitations of measuring devices in a given situation. — 42, 43

Process VI EXPERIMENTING

In order for a student to demonstrate competence in using the process of experimenting, he should be able to do the following:

Use suitable experimental procedures in seeking solutions to problems, including possibly:

Behaviors **Questions**

1. Design an investigation appropriate to the problem:

   a. Select, clarify, and state in testable terms (perhaps as an answerable question) the primary variable to be investigated. — 67, 71

   b. Control the variables appropriately so that logical conclusions may be drawn with regard to the primary variable. — 68

Process VI EXPERIMENTING (cont.) | Questions

c. Distinguish between dependent and independent variables. 69, 72

2. Perform the investigation:

a. Design, construct, or select, and successfully utilize apparatus to assist in data gathering, where appropriate. 70, 76

b. Employ the processes of observing, comparing, quantifying, classifying, and measuring to gather data.[1]

c. Repeat the data gathering a sufficient number of times to improve reliability and under sufficiently varying conditions to account for the influence of different variables. 75, 77

d. Record and organize the data gathered in a logical form.[1]

3. Utilize the processes of inferring and predicting to interpret the data collected, answer the original problem, and lead to the posing of new problems and the design of new experiments to investigate them. 74

Process VII INFERRING

In order for a student to demonstrate competence in using the process of inferring, he should be able to do the following:

Behaviors | Questions

1. Draw warranted generalizations from a body of data. 78, 82

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[1]There are no questions specifically designed to assess this behavior (because it does not lend itself to short-answer questions) however, it has been included for logical continuity and completeness in the blueprint.

Process VII INFERRING (cont.) Questions

2.	Identify the factor most likely to have caused a given change in a system.	92, 95
3.	Identify and specify observations which would be needed to justify a particular generalization.	94, 96
4.	Be able to distinguish between a statement based directly on observations and one which is an inference or a generalization.	12, 79
5.	Be able to draw more than one inference in situations where the data allows this.	73, 85
6.	Be able to test an inference by collecting further data.	80, 83
7.	Recognize which data are necessary and sufficient to support an inference or a generalization.	81, 86

Process VIII PREDICTING

In order for a student to demonstrate competence in using the process of predicting, he should be able to do the following:

	Behaviors	Questions
1.	Be able to detect or demonstrate trends in data (presented in many different ways) and be able to use these trends to predict by extrapolation and/or interpolation.	88, 89
2.	Devise and use simple means of checking the accuracy of the predictions made.	84, 90

Process VIII PREDICTING (cont.)	Questions
3. Recognize and use pertinent arguments, reasons, or principles to justify a prediction.	91, 93
4. Demonstrate an operational knowledge of the necessity for multiple and reliable observations prior to prediction and an unwillingness to offer predictions in the absence of such observations.	8, 87

GLOSSARY

The terms and phrases used in the blueprint which do not have precise behavioral or scientific meanings, or whose common meanings are either imprecise or somewhat different from their usage in the blueprint, are defined as follows:

Factors: For example, gravity, physical properties, spatial relationships, heat, light, magnetism, electrical forces.

Interaction: The process by which two or more objects or forces or systems influence each other causing changes in one or more of the interactants.

Operational knowledge: The ability to use the concepts, constructs, etc. under consideration without necessarily having command of the technical vocabulary associated therewith.

Physical Properties: For example, phase, motion, color, mass, length, volume, area, density, temperature.

Simultaneous properties: Properties which are to be considered together. For example, objects which are at the same time red and square versus objects which are not at the same time red and square.

System: An assemblage of objects and factors which affect and/or characterize those objects, arbitrarily selected for study from the totality of objects and factors.