A TEST IN FIRST YEAR CHEMISTRY¹

J. CARLETON BELL

Brooklyn Training School for Teachers

In the development of tests of intelligence a distinction has been drawn between knowledge tests and performance tests. One of the chief criticisms that have been made of the tests in the Binet scale is that they are too specific, that they call for relatively isolated bits of knowledge, that they are more indicative of the range of acquired information than of native abilities. Therefore we find other investigators, as Goddard, Healy, Terman, and Pintner, turning their attention to performance tests as more symptomatic of basic intelligence.

In the experimental investigation of attainments in school subjects a similar distinction may be made between tests of the range of information and tests of skill in performance. Here the performance tests have received by far the most attention. For this there are at least two reasons. First, the greater part of the elementary school course is devoted to formal, instrumental, rather than content subjects. The work in reading, in arithmetic, in drawing, in handwriting, and to some extent in spelling and grammar has been directed chiefly to the development of a generalized ability to meet situations rather than to the acquisition of specific informational content. That such ability is valuable and necessary is not to be denied, but there is reason to believe that the formal, drill aspects of elementary school work have been over-emphasized, to the neglect of knowledge of physical and human nature, history, literature and art. The same is true in large measure of the high school. Second, it is easier to measure such assumed general ability than it is specific information. All of our reading scales are constructed on the basis of testing the general ability to read, with little regard to the content of what is read. We have no scales to measure the child's knowledge and appreciation of poetry, of biography, of history, of novels, of short stories. All work in elementary arithmetic is necessarily formal, but until recently we have confined our attention to the four fundamental operations and a few random problems in reasoning. Few attempt have been made to explore the child's knowledge of fractions, of decimals, of denominate numbers,

¹ A preliminary account of this study was read before the Chemistry Section of the Central Association of Teachers of School Science and Mathematics at Columbus, Ohio, December 1, 1917, and appears in the May number of *School Science and Mathematics*.

of percentage, of involution and evolution. No scientific studies have yet been made of the school child's knowledge of animal and plant life, of the structure and functioning of his own organism, of his relations with his social environment, and we have only a few fragmentary efforts to determine his knowledge of geography and history. The range of possible knowledge in these subjects is so great and the attainments of a given child depend so much upon the circumstances of his environment that it is extremely difficult to construct tests that will give an adequate measure of the range of his information.

In attempting to determine the attainments of high school pupils in a natural science, like chemistry, we are again confronted by the performance and the informational aspects of the situation. We may ask what can the child *do* in chemistry, or we may inquire what does he *know* about the facts of chemistry. A complete measure of his attainments would, of course, include both. In determining his performance we might take him to a chemistry laboratory and confront him with a series of chemical situations typical of the work in elementary chemistry. This would be the most concrete and thorough test of his performances in chemistry, but would involve much time, expense, and effort in carrying out the test. A second method of procedure would be to confront him with a list of problems and ask him to indicate on paper what he would do in the solution of these problems. This type of test lacks the concreteness of the actual laboratory situation, but requires less time and expense, can be conducted with a large group of students at one time, and has the added advantage of affording a test of the pupil's scientific imagination. The writer believes that this type of problem test offers a rich field for experimental investigation which has been almost entirely neglected.

The present study was confined to the informational aspect of elementary chemistry. The question proposed was, what do high school pupils who have had one year of chemistry know about the subject? The study was further limited geographically to certain representative high schools in the state of Texas. The first problem in such a study is to determine the scope of elementary chemistry and the relative importance of the main topics taken up in the course. The ideal method of procedure here would have been to ascertain from the teacher of chemistry in each of the schools in question the topics covered in the course, and the appropriate amount

of time and attention devoted to each. This would have taken more time than could be allowed for the preliminary work, so recourse was had to a study of representative texts in elementary chemistry and of the recommendations sent to high schools by the chemistry department of the University of Texas. These recommendations are generally followed in the teaching of chemistry in Texas high schools, and serve to standardize the treatment of the subject. The next task was the selection of the specific questions that should constitute the test. If time had allowed, it would have been desirable to make an extensive preliminary study here by formulating a considerable number of questions on each topic, perhaps 200 or 300 in all, and submitting these to a large number of representative teachers of chemistry in different parts of the country (or perhaps merely to the teachers of the schools to be studied) with the request that they either rank the questions in the order of their importance, or indicate in some other manner the ones they considered most important. From a statistical treatment of the returns one could readily determine the questions that were considered of greatest importance by teachers of chemistry, and on this basis one could construct a test that would cover the most important points in elementary chemistry. In the present instance such an elaborate study was inexpedient, so that the questions had to be selected on the basis of individual opinion, supported by personal consultation with as many teachers of chemistry as could be interviewed.²

In formulating these questions the effort was made to state the question briefly, clearly and unambiguously, to call for such information as could be given in a few words, and to so frame the question that the answer could be marked as either right or wrong. All answers were to be written on the question sheet. When the papers were returned, however, it was found that some of the answers were partly right and partly wrong, so it was decided that a better indication of the abilities of the pupils would be afforded by giving one credit for correct answers, one-half credit for answers partly correct, and no credit for those entirely wrong. At the top of the sheet were blank spaces in which the pupil was asked to write his name, the name of the school, the date, the amount of chemistry he had studied, and the date of this study. The questions proposed were as follows:

²For this work the writer desires to express his obligation to Mr. R. G. Upton, an experienced teacher of chemistry, who was at that time assistant in the school of the Art of Teaching at the University of Texas.

CHEMISTRY TEST

1. What chemicals are liberated in electrolysis of water?
2. What gas is given off by the action of yeast in bread dough?
3. Name two chemicals used in making oxygen.
4. Express in cubic centimeters one litre.
5. Name two substances used in making hydrogen.
6. Define oxidation.
7. Define reduction.
8. Name four processes of purifying water.
9. What is a deliquescent substance?
10. Name two gases either of which might be used to bleach cloth or flowers.
11. Name two very common organic acids.
12. Name two chemical compounds used in making common salt.
13. Write the reaction for sulphuric acid on potassium hydroxide.
14. Name the two most abundant elements in the atmosphere.
15. Name two commercial sources of ammonia.
16. Is air a chemical or physical mixture?
17. Why does ammonia water always feel cold when it comes in contact with the hands?
18. Name substances used to make aqua regia.
19. Name four basic hydroxides.
20. Name the commercial uses of the nitrates.
21. What are the properties of carbon bisulphide?
22. Give chemical name of CaSO_4 , H_2S , Na_2SO_3
23. What is the valence of H., of O., of Ca., of SO_4
24. Name the members of the chlorine group.
25. How many grams of water are formed by the combustion of 10 grams of hydrogen in the air? (Work on this paper).

Returns were received from the chemistry classes in the high schools of sixteen Texas cities. The city of Galveston returned papers from an elementary class and from an advanced class, and if these are counted separately (as is done in the tables) we have data from seventeen groups. Texas high schools begin their year's work about September 15. The papers were sent to the schools about May 10, and the tests were given about May 15. As the schools close about June 1, the work of the year had been practically completed. The pupils in fourteen of these schools had thus studied chemistry just eight months. In San Antonio the work had been begun late in the year, so that three months' study was reported. Thus San Antonio and the two groups from Galveston (one with three months' study and one with twelve months', should be considered by themselves.

THE RESULTS

A summary of the results is presented in Table I. The cities in which the high schools are located are given in alphabetical order. Column one gives the number of pupils in each group. It is probable that in the larger cities, as Fort Worth, Dallas, and Corpus Christi, these groups were divided into two or more sections, but there was nothing in the returns to indicate the sections. The classes are seen to be of moderate size, and are probably representative of chemistry classes in towns of less than 100,000 inhabitants. Each group is composed of both boys and girls, and of the entire number of four hundred papers received, one hundred and ninety-eight were from boys and two hundred and two from girls. It is somewhat surprising that so much interest should be shown in chemistry by girls. It is ordinarily assumed that girls prefer such studies as languages, literature and history, and that in elective courses in natural science boys predominate. It would be interesting to know whether studies in other parts of the country would show a similar equality in numbers of boys and girls taking chemistry.

As the returns were received, the papers were carefully gone over and each answer was marked right, partly right, or wrong. These marks were then transferred to score sheets presenting the individual responses made by the pupils to each question. Each pupil's total score was then computed and expressed as a per cent. of the maximum. The average of these per cent. scores was taken as the index of the group. Likewise the number of correct responses made by the group to each question was computed and expressed in terms of per

TABLE I
Percentage Score on Each Question

	No. Pupils		No. of Question																									Average	No. Boys	Av. for Boys	No. Girls	Av. for Girls
	Months																															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25					
1. Beeville.	23	8	87	91	83	9	76	58	48	35	30	72	83	35	61	65	24	48	22	67	67	24	24	70	78	83	26	56	9	54	14	57
2. Brownwood	17	8	100	100	100	83	100	95	89	75	64	83	95	75	75	92	50	95	42	86	97	64	31	61	89	100	39	78	11	75	6	76
3. Coleman	15	8	100	100	97	74	93	67	63	53	93	80	87	40	74	80	17	80	63	74	87	50	40	60	60	90	13	69	3	72	12	68
4. Corpus Christi. . .	44	8	83	82	77	68	88	86	83	40	11	65	31	61	97	69	12	48	48	73	91	22	15	64	99	98	18	59	20	64	24	55
5. Dallas	46	8	100	98	62	42	96	89	84	77	39	76	51	46	64	84	34	70	28	58	87	40	24	85	86	57	63	63	16	76	30	56
6. Del Rio	13	8	100	100	69	0	69	69	77	65	69	81	92	69	89	81	8	69	58	81	69	8	15	77	85	92	27	65	8	61	5	71
7. Denton	18	8	95	95	36	67	97	33	33	67	28	64	19	61	75	75	6	95	39	11	58	19	22	47	70	92	6	52	14	54	4	44
8. El Paso	21	8	95	91	21	79	57	76	79	53	55	62	55	60	95	88	26	76	60	84	76	41	31	76	88	95	21	65	15	66	6	55
9. Ft. Worth	50	8	97	99	71	77	79	76	66	65	76	83	44	68	75	91	13	78	18	77	89	47	12	66	85	98	54	69	16	71	34	68
10. Garland	16	8	94	81	81	44	94	50	19	53	31	59	31	28	3	56	22	31	19	91	78	22	9	41	3	88	0	45	7	48	9	42
11. Lockhart.	14	8	100	100	82	72	93	100	100	89	93	68	93	93	97	93	57	72	29	61	100	39	46	75	93	100	72	81	7	87	7	75
12. Mexia	21	8	95	95	50	86	62	55	19	53	53	74	0	17	50	57	2	67	33	33	53	26	0	57	36	91	10	47	12	53	9	39
13. San Marcos	28	8	70	29	7	32	29	39	7	41	0	57	43	21	57	54	2	39	29	9	86	9	34	57	61	63	0	36	13	38	15	34
14. Uvalde.	10	8	90	100	0	80	50	60	60	45	60	65	30	20	30	70	0	60	0	40	45	55	0	50	45	40	40	45	6	44	4	47
Average.	24		93	90	60	58	77	62	59	58	50	71	54	50	67	75	20	66	35	60	77	33	22	63	70	85	28	59	11	62	13	56
15. Galveston, Adv . .	14	12	100	93	79	72	89	100	86	72	68	72	79	79	97	86	39	86	43	82	89	57	18	86	86	100	36	76	8	79	6	73
16. Galveston, Elem . .	14	3	90	7	50	93	50	57	0	46	7	43	11	39	61	82	0	79	21	0	68	14	0	29	50	0	0	36	10	39	4	29
17. San Antonio	36	3	97	83	67	60	78	76	33	54	72	71	58	53	56	88	32	51	50	39	56	40	18	61	60	58	28	58	23	60	13	54

cent. of the maximum. These percentages for each question are shown in Table I in the columns numbered from 1 to 25. The column marked Average presents the average total score or index for each group. Examination of this column shows that the average index for the fourteen schools whose pupils had studied chemistry for eight months was 59. The range is from 81 (Lockhart) to 36 (San Marcos). This ratio is well over two to one, and shows that there is a vast difference in the chemistry teaching in Texas high schools. This sets an interesting problem which calls for further investigation. What is the reason for this wide range of scores? That it is due to individual differences in pupils is scarcely likely. One might think that in the larger schools the individual pupils do not get as much attention, and hence their showing is not so good. Inspection of the table, however, does not bear out this assumption. On the contrary, the larger schools, Fort Worth, Dallas, and Corpus Christi, show a combined score that is well above the average, while the small schools, Garland, Mexia, and Uvalde, are near the bottom of the list. In the absence of other evidence we suspect that the chief reason for the difference is to be found in the individual teacher, and that in general the larger towns pay the better salaries and get the better teachers. Lockhart, Brownwood and Coleman, however, all small towns, stand at the very top of the list, and thus tend to weaken the force of this hypothesis.

Table II gives the percentile distribution of the individual scores made in each school. It will be seen that the score of the best pupil is usually more than twice as good as that of the poorest in the same class, and in one case (San Marcos) it is almost four times as good. Marked exceptions to this are Brownwood and Lockhart, where the pupils are fairly close together, and all stand high. From the entire body of four hundred pupils, only one (Roland Bond, of Dallas) made a perfect score, or 100 per cent. Other high scores were made by Pliny Dell Valle, Dallas (98 per cent.); J. D. Miller, Dallas (92 per cent.); Alfred Harrys, Denton (94 per cent.); Hilmar Karbach, Lockhart (94 per cent); and Harry Galloway, Lockhart (92 per cent). On the other hand the lowest score (16 per cent.) was made by a boy in the San Marcos school, and of the lowest ten scores six are to be credited to that school. This difference between the highest and the lowest schools can be clearly seen in Table I. Lockhart, with an index of 81, had 100 per cent. correct on six questions, and 75 per cent. or better on sixteen of the twenty-five questions, while the

TABLE II
Range of Individual Scores in Each School

	Lowest	Percentile									Highest
		10	20	30	40	50	60	70	80	90	
1. Beeville	18	36	38	38	50	56	58	62	66	74	90
2. Brownwood	66	68	70	76	78	80	82	82	86	86	88
3. Coleman	34	50	60	62	70	74	74	80	80	84	88
4. Corpus Christi	42	48	50	54	56	60	64	66	72	78	86
5. Dallas	40	46	52	56	60	66	68	70	78	80	100
6. Del Rio	40	56	58	58	62	66	70	74	78	78	82
7. Denton	32	34	38	42	46	50	52	54	62	86	94
8. El Paso	46	46	52	60	62	68	70	72	78	78	84
9. Ft. Worth	38	58	62	66	68	70	72	74	78	80	84
10. Garland	24	34	36	38	40	44	46	46	52	60	70
11. Lockhart	66	72	76	78	80	82	84	84	88	90	94
12. Mexia	28	34	38	40	42	48	50	52	54	64	70
13. San Marcos	16	18	22	26	34	38	46	48	52	52	62
14. Uvalde	22	30	32	38	44	46	46	58	58	58	78
15. Galveston, Adv.	50	62	68	70	72	84	84	84	84	86	88
16. Galveston, Elem.	20	28	32	34	36	36	36	40	42	44	54
17. San Antonio	30	32	38	42	48	56	60	68	76	82	86

lowest question had 29 per cent. San Marcos, with an index of 36, made no higher score than 86 per cent. on any question, had only eight questions over 50 per cent., received scores of less than 10 per cent. in seven questions, and failed entirely on two questions. The widest difference between extreme scores is seen in Beeville, where the range is from 18 to 90.

In addition to the scores of the fourteen schools already discussed, Table I presents the results from the two classes in Galveston and from the San Antonio high school. Evidently the elementary class in Galveston had not gone very far in chemistry, for on six of the questions no score at all was made. The index for the class was 36, which although it is not high, is proportionately much better than the showing made by some of the schools after eight months of study. The advanced class, with twelve months of study to its credit, presents an index of 76, which is higher than that of any other school except two, but is scarcely a showing adequate to the greater amount of time spent on the subject. The large class in the San Antonio

high school, on the other hand, after only three months of study, attains an index of 58, a score within one point of the average of the indices of all the eight months schools. Moreover, an inspection of the scores made on the individual questions shows that the attainment was remarkably even and well-balanced. With the time and other factors included in the reckoning perhaps San Antonio makes the best showing of any of the schools.

Attention has already been called to the fact that the number of boys and girls taking the test was practically equal. This does not apply to the individual schools. In the larger schools, as Fort Worth and Dallas, the girls outnumber the boys approximately two to one, while in the smaller towns the boys are usually in the majority. In the general average of attainments, however, the boys are distinctly superior to the girls, the scores standing 62 for boys to 56 for girls. This is not only true of the general average but applies to the schools individually, only four classes of the seventeen showing a higher score for the girls than for the boys. The superiority of the boys is especially marked in Corpus Christi, Dallas and Lockhart, while in Fort Worth and San Antonio it is not so pronounced. It is noteworthy that the group of pupils having the highest ten scores is composed exclusively of boys. Likewise the lowest two scores were made by boys, out of the lowest ten five were boys and five were girls. So far as it goes, therefore, this investigation supports the contention that boys are more variable than girls.

Table I shows not only the average score of each school on each question, but also the average scores of the fourteen schools that had had chemistry for eight months. These averages are made directly from the school scores, and are, therefore, on the basis of the same number of pupils for each school. It is of interest to compare the different questions from the point of view of the responses made to each. Table III presents the questions in order of increasing difficulty, or at least in the decreasing magnitude of the average score. As might be expected, the electrolysis of water is the most familiar, with the action of yeast in bread dough a close second. These facts are easily retained, owing to their connection with daily life. The knowledge of the members of the chlorine group is more technical, and it is somewhat surprising that the question receives such a high score. These three questions are, therefore, in a group by themselves. The next seventeen questions show a regular decrease in score from 77 to 50. Seven of these questions lie within

TABLE III.

Questions Arranged in Order of Increasing Difficulty.

Per cent.	No. of Question.	Question.
93	1.	What chemicals are liberated in electrolysis of water?
90	2.	What gas is given off by the action of yeast in bread dough?
85	24.	Name the members of the chlorine group.
77	5	Name two substances used in making hydrogen.
77	19.	Name four basic hydrides.
75	14.	Name the two most abundant elements in the atmosphere.
71	10	Name two gases either of which might be used to bleach cloth or flowers.
70	23.	What is the valence of H, of O, of Ca, of SO_4 ?
67	13.	Write the reaction for sulphuric acid on potassium hydroxide.
66	16.	Is air a chemical or physical mixture?
63	22.	Give the chemical name of CaSO_4 , H_2S , Na_2SO_3 .
62	6	Define oxidation.
60	3	Name two chemicals used in making oxygen.
60	18.	Name substances used to make aqua regia.
59	7.	Define reduction.
58	4.	Express in cubic centimeters one litre.
58	8.	Name four processes of purifying water.
54	11	Name two very common organic acids.
50	9.	What is a deliquescent substance?
50	12.	Name two chemical compounds used in making common salt.
35	17.	Why does ammonia water always feel cold when it comes in contact with the hands?
33	20.	Name the commercial uses of nitrates.
28	25.	How many grams of water are formed by the combustion of 10 grams of hydrogen in the air?
22	21.	What are the properties of carbon bisulphide?
20	15.	Name two commercial sources of ammonia.

a range of five points (63 to 58). The last five questions are so much lower that they form another distinct group. Perhaps Question 17 deals with a phenomenon that is more physiological than chemical, but the facts are usually brought out in connection with laboratory work. Evidently the commercial uses of nitrates and of ammonia receive very little attention in these chemistry classes. Is this another indication of abstract formalism in science teaching, and of neglect of the concrete applications of the science?

Table IV affords a comparison of the attainments of the best ten and the poorest ten of the entire four hundred pupils. Of the twenty easier questions the good group made 100 per cent. on fifteen, 95 per cent. on four, and 85 per cent. on one. Their lowest score was

TABLE IV.
Average of Highest Ten and Lowest Ten Pupils

	Average Total Score	No. of Question															
		1	2	3	4	5	6	7	8	9	10	11	12	13			
Average of highest ten pupils	93	100	100	95	100	100	100	100	95	100	95	100	100	100			
Average of lowest ten pupils	20	65	20	5	50	10	20	0	30	10	35	20	5	10			
						14	15	16	17	18	19	20	21	22	23	24	25
Average of highest ten pupils						100	55	100	70	85	95	70	75	100	100	100	80
Average of lowest ten pupils						50	5	30	10	5	50	5	0	10	30	15	0

55 per cent., on the commercial uses of ammonia. The scores of the lowest ten seem to be quite erratic. They agree with the others in showing the greatest familiarity with the components of water, but otherwise there is no agreement either with the highest ten or with the entire group. On three questions they get 50 per cent. One of these is purely mathematical, one deals with the elements in the atmosphere, and only the last (name four basic hydroxides) depends strictly on a study of chemistry. Three of the questions (Nos. 7, 21, and 25) arouse no trace of accurate response.

The present study is tentative, incomplete, and limited in its scope. It would be desirable to have more information regarding the text-book used in each school, the topics emphasized in the course, the number of recitations per week, the amount and character of the laboratory work, and the point of view of the teacher. The range of questions might well be amplified, and correlated studies should be carried on with other high school subjects. A study of school marks in chemistry should go along with such testing. It is hoped that this article may stimulate others to make similar and more thorough investigations.