Students' Competence in Verbal Reasoning and Language Skills in Their Learning Throughout the BSc-Extended Course

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***Abstract*—This paper studied students' competence in verbal reasoning, and language skills in their learning throughout a BSc-extended course. This included testing their information processing and verbal reasoning skills, and their understanding of the meanings of some important non-technical words and phrases used in the chemistry curriculum. Fourteen questions were used to test aspects of language and verbal reasoning difficulties associated with learning chemistry. The questions tested their understanding of words such as qualitative and quantitative, description and explanation, ability to convert statements into equations, ability to represent information as diagrams, direct and inverse proportion reasoning, relationships between words and applications of laws. Results indicated that many students had difficulties with both language and verbal reasoning. Many of these difficulties were due to their not understanding the words used in the phrases or sentences given. The results suggest that it is essential, while teaching, to ensure that students understand the words used and also that they must be trained in verbal reasoning and information processing (e.g. converting statements into equations and diagrams).**

***Index Terms*—verbal reasoning, problem solving, non-technical words, language skills**

I. Introduction

The subjects in this study were following a BSc-Extended programme at North-West University (Mafikeng Campus). They came from diverse backgrounds where English was generally not their first language. The programme is a four year degree, whereby the students take two years to complete the normal first year of a BSc degree, and then they join the normal BSc students for the last two years of their degree. Thus the first semester of a normal BSc is equivalent to the one year of the extended programme, and the second semester is equivalent to the second year of the extended programme. The minimum entry requirements for the extended programme are a minimum of 40% in English, Mathematics and Physical or Life Sciences in the South African matric certificate, whereas the normal BSc requires at least 50% in these subjects.

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Learning Chemistry involves not only the correct use of concepts and application of symbols, it also involves clear understanding of words used, and their meaning. Students fail in chemistry, not only due to lack of chemical knowledge and skills, but also due to language problems [1], such as the inability to understand the action words in questions and inability to use direct and inverse proportional reasoning skills.

The majority of the students who enter the extended programme are under-prepared and do not possess the necessary language skills required in learning chemistry in higher education institutions. Learning chemistry is difficult for the students, and challenges may arise not only from the use of symbols to represent concepts, but also from the language used to communicate the chemistry concepts, which includes both technical and non-technical words. Studies have shown that many students do not have the necessary basic skills required for learning, particularly for learning mathematics and science "unpublished" [2].

The scope of this paper is limited to the study of students' ability to carry out simple verbal reasoning and their understanding of the meanings of some non-technical words and phrases used in the chemistry curriculum.

Fourteen questions were used to test aspects of language and verbal reasoning difficulties in learning chemistry. Questions used included the understanding of words such as qualitative and quantitative, and description and explanation, ability to classify statements (as facts, principles, laws, theories etc), ability to convert statements into equations, ability to represent information in diagrams, direct and inverse proportion reasoning, relationships between words and applications of laws. Students' responses to the questions will be discussed in this paper.

II. Literature Review

Various aspects of chemistry education and cognitive skills associated with methods of learning chemistry have been studied [3]. Two learning theories which provide the theoretical basis for this research will be discussed here.

A. Constructivist Learning Theory

The underlying concept in the constructivist learning theory is the role which learning experiences in

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conjunction with learning atmosphere play in learning [3], [4] Two key concepts within this theory which relate to the construction of an individual's new knowledge are accommodation and assimilation. Accommodation refers to reframing the world and new experiences into the mental structures already present. Assimilation involves the incorporation of new experiences into old experiences and this helps an individual to develop new outlooks, rethink and evaluate what is important. In this theory, teachers are regarded as facilitators whose role is to aid the student to reach new understanding. Instead of having students relying on information provided by facilitators, it postulates that students should be exposed to data and primary sources, and should be able to interact with other students. The constructivist teacher provides tools such as problem solving and inquiry based learning activities with which students formulate and test their ideas, draw conclusions and convey their knowledge in a collaborative learning environment [3].

B. Information Processing Theory

This theory is based on the idea that people process information they receive rather than merely respond to stimuli. The theory encompasses many cognitive processes which include perception, reasoning, problem solving and conceptualization [5], [6]. People process information with amazing efficiency in order to perform difficult tasks such as problem solving and critical thinking. Ref. [7] showed that non-technical words associated with science were a cause of misunderstanding for students. The study indicated that words which were understandable in normal English usage sometimes changed their meaning when transferred into or out of a science situation. For example, the word "volatile" was used by students to mean "unstable" or "flammable" whereas its scientific meaning of "easily vapourised" was not clear to them. Ref. [8] studied the ability of American first year undergraduate students to solve "language" problems in chemistry. They noticed that students could solve problems of increasing difficulty until they had to work with one additional language item they did not understand. In single step problems the subjects in Ref. [8]'s study could solve 91% of common language problems, and 82% of chemical language problem. In three step common language problems the success rate was 86%, but in three-step chemical language problems this dropped to 32%. They suggested that students' exposure to chemical language should be intensified, that teachers should not assume that students are familiar with chemical terms and that terms should be introduced carefully. Ref. [9] noted students' success rates in chemistry may not necessarily be related to the subject matter itself but to the way of teaching it. Ref. [3] indicated that difficulties in learning chemistry can be precipitated by a lack of chemistry language skills.

Ref. [10] studied the comprehension of some non-technical words by form four students in Malaysia, in different streams: art, engineering and science. They compared the results with those obtained by Ref [11]. They found that students from the art class scored very low compared to those in engineering and science. They also indicated that 82% of the science students and 76% of engineering students communicated in English at home. But only 28% of the arts students spoke English at home. Their findings indicate that students speaking English at home showed a higher comprehension level than those students who do not speak English at home.

III. Objectives and Method of Study

The main objective of the study was to identify the various types and extent of students' difficulties with language and verbal reasoning that would hinder effective learning of chemical knowledge.

The procedure used for the study involved among others the following steps:

- Identification of non-technical and non-conceptual words/phrases/sentences in the recommended texts and reading material, and in tutorial questions, question papers and practical instruction sheets whose meaning is important for learning, understanding and using chemical knowledge.
- Identification of the types of verbal reasoning (both qualitative and quantitative) that is essential for learning and use of chemical knowledge.
- Design of a questionnaire which tested the understanding of the words/phrases/ sentences identified above and tested verbal reasoning ability.
- Discussion of the performance of students and make suggestions for improving the ability of students to learn and use knowledge effectively.

IV. Administration of the Test

The first and second year extended programme students in 2013 were tested in October-November 2013, and the 2014 first year students were tested in May 2014. For the 2013 tests, all the questions were given in one question paper, and the time allowed for completion of the paper was two hours, whereas for the 2014 students the question paper was divided into two sections (i.e. Section A and Section B. Two hours were allocated for the completion of both sections.

In the question paper students were required to give their student numbers, indicate their level of study and their English achievement at high school. Although English was generally not their first language, the students had the option to take either the first or second language English curriculum at school.

V. Results and Discussion

The questions paper that was used to test language (non-technical words) and verbal reasoning skills is given below in appendix A, which also includes the results of each question, expressed as the percentage of students who answered each question correctly.

VI. Discussion

The results varied for the different groups. Questions 1-3 tested language skills. In question 1, the performance

of students in all questions was generally good; correct answers in the range 60% to 100%. Question 1.7 was however, poorly answered; correct to only about 40%. The majority of students who answered question 1.7 incorrectly matched the word "deduce" with the phrase breaking up of a substance," Not understanding this word would seriously hinder not only their learning but also their ability to answer questions correctly at examinations.

Question 2 tested ability to differentiate between descriptive and explanatory statements. Descriptive statements state experimental information about what is observed, whereas explanatory statements give reasons to experimental facts and laws. In chemistry, explanations are given in terms of the particles present and their properties. The performance of the second year 2013 group was below average in questions 2(e) and (f), with scores of 58% and 50% respectively, although the other groups performed much better. The average performance of first year 2013 and 2014 were 72% and 78% respectively. The second year 2013 group performed worst with about 64% of correct answers.

In question 3 the performance was poor for both first and second year 2013 students. The 2014 group performed better than the 2013 groups. Question 3b was very poorly answered by the 2013 groups: correct percentages were 20% and 22% respectively. About 60% of the first year 2013 and 50% of the second year 2013 students failed to answer the questions. Inability to differentiate between the terms 'quantitative' and 'qualitative' statements will seriously hinder learning.

Question 4 tested the understanding of some words used to describe important concepts. Students were given incorrect statements, and they were expected to point out clearly why the statements were not correct, and also to modify the statements to make them correct. Question 4(a) was used as a clue and question 4(b) and (g) were omitted in 2014. On the average, the performance of all groups was poor: less than 36%.

Question 5 tested ability to convert quantitative statements into equations. Students were expected to identify all the variable quantities in the statements and give symbols to them. The symbols for the different quantities was given in the question paper, and the solutions to question (a) was also given in the question paper, to aid students on how to answer parts (b)-(g). The lowest scores were for questions 5(e) and (f): the second year 2013 scoring 4% in 5(e) and first years 2013 scoring only 18% in 5(f). The performance of the 2014 group was much better, ranging between 65%-85% on all questions, except for question 5(f). Most students did not answer both parts of the questions; they wrote the relationship between variables, but did not assign symbols to them.

Questions 6 tested students' ability to represent verbal information in a form of a diagram. The performance of students in this question was very poor those who answered correctly were 10% for first year 2013, 25% of first year 2014 and 0% for the second year 2013. The average result for question 6 for all groups was below 20%. Students failed to realize that they had to consider the distance travelled along the main road; instead they added all the values which both cars had travelled.

Question 7 tested the important aspects of inverse proportion reasoning. In question 7(a) students were required to identify the variable quantities in the given statements: the correct answer is "number of men and time," The performance of students in this question was very poor those who answered correctly were 45% for first year 2014, 35% for first year 2013 and 27% for the second year 2013. The students could have solved the problem in two methods by either (a) verbal reasoning or (b) using equation, and they failed to do so.

In question 8(a) students were asked if six chocolates cost 42 rands, and how many chocolates could be bought for 30 rands? Students were required to first determine the price of one chocolate then use that value to calculate how many chocolates can be bought for 30 rands. In question 8(b) students were asked to identify variable quantities, which were the number of chocolates and price of chocolates. The performance was poor: for the first year in 2013 was 58% for second year 2013 was 31%.

Question 9 tested analogical reasoning: relationship between words, and categorization of concepts. In question 9(a) the correct option was (iv) litre. The performance of students in this question was very poor those who answered correctly were 50% for second year 2013, 39% of first year 2014 and 24% for the first year 2013. Most students did not link the first part of the question which gave them the relationship between the concepts that was needed (i.e. quantity and unit, not quantity and apparatus used to measure it). The majority of them chose option (i) measuring cylinder. Questions 9(a) and (c) were poorly answered (below 50%) although question 9(b) was well answered (over 90%).

Question 10 tested the students' ability to reason quantitatively and how logical conclusions can be drawn from given statements. The correct statements were options (i) and (iii). 27% of both groups elected only option (i), just over 50% chose option (iii), but only 5% chose both options (i) and (iii) correctly. The average performance of both groups was just above 40%. The majority of students did not realise that Tshiamo and Dineo's marks were equal, whereas Pule's mark was half that obtained by them. Students need training on how to draw conclusions from given verbal statement, either by deriving an equation or verbal reasoning.

Question 11 tested students on comprehension some simple concepts that are important in chemistry. In the test for the 2013 groups, a phrase was given without including values, whereas for the 2014 group the phrase was given including an example, although the types of questions asked were similar. The performance of students in this question was very poor those who answered correctly were 44% for second year 2013, 37% of first year 2013 and 76% for the first year 2014

Question 12 tested whether students use verbal reasoning or an equation to do calculations involving a simple concept, mass fraction. In question 12(a) about 20% for first year 2013 and 35% for second year 2013 students

did not start the solution with the equation that relates the fraction and mass of a compound. The performance in part (b) was very poor with correct answers: 7% for first year 2013 and 0% for second year 2014. Many of the students did not attempt to answer the question, and wrote "confused" next to the question asked. This is a clear indication that many students are unable to organise variables into equations and carry out step by step procedures in simple calculations.

Questions 13 and 14 (tested on all groups) tested the ability to draw conclusions from verbal statements by using diagrams (Venn diagrams). In Question 13 students were given a phrase, in which they were required to make a logical conclusion about the statements given. Question 14 was linked to question 13 whereby students were required to use their thinking skills to connect the statements given in question 13 with the diagrams given in question 14. All groups performed poorly, below 19%. Students were not able to draw conclusions using information from verbal statements, or to represent the information in diagrams.

VII. Conclusion

The main objective of the study was to test students' competence in verbal reasoning and language difficulties that are important for learning of chemistry. Students' competence was consistently poor. For example

- About 35% the second years 2013 failed to distinguish between descriptive and explanatory statements.
- About 55% of all students failed to distinguish between quantitative and qualitative statements.
- About 70% of all students tested did not understand the meaning of words used to describe important concepts in sentences/phrases.
- About 50% of students could not convert quantitative statements into equations.
- Above 75% of all groups tested was unable represent verbal information in the form of a diagram.
- About 60% of all groups tested failed to identify the information provided by quantitative verbal reasoning (inverse proportion).
- About 55% of the second years in 2013 failed to identify the information provided by a quantitative verbal reasoning (direct proportion).
- About 63% failed to identify the comprehension some simple concepts that are important in chemistry.
- About 82% failed to use verbal reasoning or an equation to do calculations that involved simple concept used in chemistry.
- 80% were unable to draw conclusions using Venn diagrams

Most students who enter the BSc-extended programme do not possess the learning skills of understanding of concepts and new relations presented to them in texts. They need further training on how to acquire and apply these learning skills. Therefore teaching of chemistry should not merely involve the transmission of information but also effective training in learning and thinking skills.

Appendix A Test Question Paper and Results

Question 1

Tested the understanding of the non-technical words/phrases often used in chemistry. It was based on matching words/ phrases in column A with those words/ phrases in column B.

Column A (Words/Phrases)	**Column B (Phrases/Statements)**		**% correct**		
1.Analyse 2. Aqueous solution 3. Combustion 4. Compare 5. Composition of a substance 6. Constant 7. Deduce 8. Dissociation 9. Emission 10. Excess reactant 11. Fraction 12. Freezing point 13. Illustrate 14. Percentage 15. Ratio 16. Simultaneous 17. Solute 18. Variable	a. A part divided by the whole b. A quantity whose value can change c. A quantity whose value does not change d. A solution in which water is the solvent e. Breaking up of a substance into simpler substances f. Burning of a substance g. Elements/ compounds present in a substance h. Examine or study something by breaking it down into parts i. Fraction multiplied by 100 j. More reactant than is needed for the reaction k. Occurring at the same time l. Release of something m. State similarities and differences n. Temperature at which a liquid becomes a solid o. The substance dissolved in a liquid to form a solution. p. The value of one quantity divided by another value of that quantity q. To make clear by examples or pictures r. To reason logically from given principles/facts		1st year (N=74) 2013	2ndYear (N=26) 2013	1st Year (N=96) (2014)
		1.1	55	46	65
		1.2	60	73	75
		1.3	88	92	91
		1.4	91	92	97
		1.5	57	42	64
		1.6	92	96	93
		1.7	42	42	43
		1.8	54	50	55
		1.9	80	89	73
		1.10	85	81	82
		1.11	70	69	97
		1.12	96	100	99
		1.13	91	85	92
		1.14	96	100	98
		1.15	64	69	83
		1.16	95	89	94
		1.17	57	81	76
		1.18	85	77	81
		Ave	**75**	**76**	**81**

Question 2

Tested the ability to differentiate between descriptive and explanatory statements.

Which of the following statements are descriptions and which are explanative statements?	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
a. The volume of a gas is inversely proportional to its pressure.	60	73	
b. The pressure of a gas is due to the continual bombardment of the walls of the containing vessel by the molecules	69	62	72
c. The percentage of oxygen in the air is 21%.	84	73	85
d. An electric current passing through a metal is due to the flow of negatively charged particles (electrons).	74	69	73
e. The rate of diffusion of hydrogen gas is higher than that of oxygen gas because hydrogen molecules, being smaller, move at a faster speed.	74	58	79
f. In a neutral atom, the number of electrons is equal to the number of protons	68	50	83
Average	**72**	**64**	**78**

Question 3

This question tested the ability to differentiate between qualitative and quantitative statements

Which of the following statements are qualitative and which are quantitative? Briefly give reasons for your answers	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
• The density of a substance is the mass per unit volume.	45	58	75
• A litre of water is heavier than a litre of ethanol	20	22	68
I. The rate of diffusion of a gas is inversely proportional to the square root of its molar mass.	32	58	66
II. Ice melts at 100 ℃	42	42	58
III. The rate of reaction increases in the presence of a catalyst	45	54	73
IV. Silver is a better electrical conductor than copper	60	58	84
Average	**41**	**49**	**71**

Question 4

This question tested the comprehension of some concepts that are important in chemistry.

The statements given below are not correct because the language/ concepts used are not correct. Point out clearly why they are not correct, and also modify the statements to make them correct.	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
a. When a water sample is heated, temperature is absorbed and therefore the temperature will increase.	26	4	
b. When the temperature (T) of a substance is kept constant, it means that T = 0	16	4	
c. The percentage of girls in a class of boys and girls is 200	19	8	6
d. The temperature of a water sample can be calculated using a thermometer.	47	19	55
e. Since 100 grams of atmospheric air contains 21 grams of oxygen, we can deduce that the percentage of oxygen in air is 21 grams.	37	31	48
f. The volume of a gas is 100 grams.	14	12	33
g. The number of molecules present in one mole of any substance is 6.0×10^{-2}	14	0	
Average	**23**	**11**	**36**

Question 5

This question tested the ability to convert quantitative statements into equations.

Convert the following statements into equations. To do this, you have to identify all the variable quantities in the statements and give symbols to them. This has been done for the three quantities in statements (a) and (b).	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
a. The resistance (R) of a wire is directly proportional to its length (l) and inversely	85	77	

	proportional to its area of cross section (a).			
b.	The concentration (c_A) of a solute A in a solution is defined as the amount (n_A) of A present per unit volume (V) of the solution.	77	62	77
c.	The difference between the masses of two objects A and B is 4 grams, A having the larger mass.	72	46	79
d.	The sum of m_A and m_B is 13 grams.	90	58	84
e.	The mass fraction of A in the mixture of two substances A and B is 0.30	18	27	64
f.	The mass percentage of an element A in a compound is 30%.	8	4	28
g.	The mass percentage of a substance A in a mixture of three substances A, B and C is defined as one hundred multiplied by the mass of A and divided the total mass of all the substances in the mixture.	53	23	67
	Average	**58**	**42**	**67**

Question 6

This question tested whether students can represent verbal information in a form of a diagram.

Two cars, 160 km apart on a main road, travel towards each other. The first car travels for 20km and takes a right turn and travels for 15 km. It then turns left and travels for another 30km, then turns left again and returns to the main road. In the meantime, the other car travels 40 km along the main road.		**% correct**		
		1st year (N=74) 2013	2ndYear (N=26) 2013	1st Year (N=96) (2014)
i.	Represent all the information given above as a diagram.	10	0	25
ii.	What would be the distance between the two cars?	7	4	22
	Average	**9**	**2**	**24**

Question 7

This question tested the important aspects of inverse proportion reasoning

Three men need ten hours to tile the floor of a house		**% correct**		
		1st year (N=74) 2013	2ndYear (N=26) 2013	1st Year (N=96) (2014)
a.	Which one of the following correctly states the variable physical quantities in the above statement? (circle the correct answer) i. Men and floor of the house; ii. Three men and ten hours iii. Number of tiles and surface area of the floor; iv. Number of men and time.	35	27	45
b.	Which of the following states correctly the type of relationship between the two variable quantities in the given statement? (circle the correct answers- more than one answer may be correct). i. Directly proportional ii. Exponential iii. Quantitative iv. Inversely proportional v. Qualitative	66	65	70
c.	How many hours will be needed by four men, working at the same rate, to tile the floor of this house?	1	4	19
	Average	**9**	**2**	**24**

Question 8

This question tested the ability to identify the information provided by a quantitative verbal reasoning statement (direct proportion reasoning).	**% correct**		
	1st year (N=74) 2013	2ndYear (N=26) 2013	1st Year (N=96) (2014)
If six chocolates cost 42 rands, calculate the number of chocolates that can be bought for 30 rands.	64	58	
State the variable quantities in this problem.	54	31	
Average	**59**	**45**	

Question 9

This question tested the analogical reasoning: relationship between words, and categorization of concepts

Circle the best response to each question below	**% correct**		
	1st year (N=74) 2013	2ndYear (N=26) 2013	1st Year (N=96) (2014)

a. Mass is to kilogram as volume is to i. Measuring cylinder ii. Bottle iii. Metre iv. Litre	24	50	39
b. Barometer is to pressure as thermometer is to i. Heat ii. Temperature iii. Fever iv. Weather	96	88	92
c. Square is to cube as circle is to i. Radius ii. Sphere iii. Round iv. Ball	42	35	36
d. Oxidation is to reduction as exothermic is to i. Heat ii. Endothermic iii. Reaction iv. Release	78	50	65
Average	**60**	**56**	**58**

Question 10

This question tested qualitative verbal reasoning, how conclusions can be drawn from given statements.

Dineo's test marks are twice that of Pule, and Pule's marks are a half that obtained by Tshiamo. Which of the following statements will then be correct?	% correct	
	1st year (N=74) 2013	2nd Year (N=26) 2013
Tshiamo has more marks than Pule,	27	27
Dineo has more marks than Tshiamo		
Tshiamo and Dineo have the same marks,	58	54
Dineo has fewer marks than Tshiamo.		
Average	**43**	**41**

Question 11:

This question tested the comprehension of some simple concepts that are important in chemistry.

A sugar solution contained in a vessel is diluted by adding water. Consider the following statements and state whether they are correct or not. Briefly explain your answers	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
a. Mass of sugar in the solution will remain constant.	31	27	56
b. The mass of the solution will increase	30	62	
c. The volume of the solution will increase,	36	46	87
d. The concentration of the sugar in the solution will decrease.	45	39	77
e. The concentration of the sugar in the solution will increase	42	46	85
Average	**37**	**44**	**76**

Question 12

This question tested whether students can carry out calculations involving mass fraction by verbal reasoning or using defining equation.

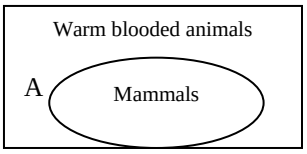
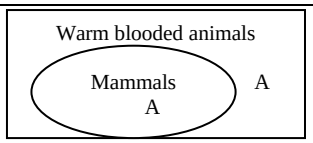
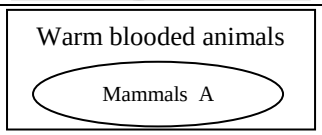
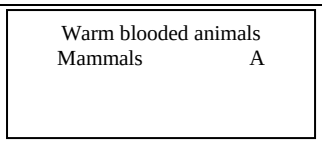
The mass fraction of oxygen in a compound is 0.20. Calculate the mass of	% correct	
	1st year (N=74) 2013	2nd Year (N=26) 2013
a. Oxygen that will be present in 50 g of the compound,	20	35
b. the compound that will contain 10 g of oxygen	7	0
Average	**14**	**18**

Question 13

This question tested the ability to draw conclusion from verbal statements.

Consider the two statements: a) All mammals are warm-blooded b) Animal A is warm-blooded	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
From these two statements would it be logical to conclude that Animal A is a mammal?	7	19	7
Average	**17**	**19**	**7**

Question 14

The information given by the statements in question 19 can be represented by a diagram, called a Venn diagram	% correct		
	1st year (N=74) 2013	2nd Year (N=26) 2013	1st Year (N=96) (2014)
Which one of the following diagrams represents correctly the information given?			
[1] 			
[2] 	14	15	7
[3] 			
[4] 			
Average	**14**	**15**	**7**

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