INFLUENCE OF FIELD-INDEPENDENCE AND WORKING MEMORY BY MULTIPLE CHOICE ITEM FORMAT ON TEST PERFORMANCE IN SCHOOL CHEMISTRY

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Abstract

Learning chemistry is a hard task for many secondary school students as a result students find it tough to score better marks in chemistry. Researchers have identified many reasons and suggested lots of alternatives to overcome difficulties in chemistry. This paper focus on whether the test item construction has any role in the response pattern of secondary school students, apart from the difficult content of chemistry. Response patterns of students for ten minor concepts in chemistry from the topics Periodic table, Chemical bonding and Organic chemistry were analysed in terms of students' level of field-independence and working memory. The results of χ^2 *tests revealed that items with visual representation helps the low field-independent students to score at par with the high field-independent students. Also, constructing structurally less complex items helps the students with low working memory at par with the students with high working memory.*

Key words: *School chemistry, Field-independence, Working memory, Test item construction.*

Chemistry is an important school subject but students face many difficulties in learning chemistry. Learning chemistry is highly demanding, on many counts even more than the other school subjects. A large number of school children perceive chemistry as difficult and therefore chemistry courses are rather unpopular (De Vos, Bulte & Pilot, 2002). Students experience a challenge in their attempt to grasp chemical concepts (Ozmen, Demircioglu, & Coll, 2007). Understanding of chemical concepts demands a deep familiarity with the interactions of the micro-particle at the microscopic level (Day, 2004; Harrison & Treagust, 1996; Vos & Verdonk, 1996). Even if students solve some chemical problems, they do not go beyond arithmetic manipulations. Understanding chemical principles behind the equations and formulae is usually lacking (Gabel, Sherwood & Enochs, 1984).

There may be several reasons for this difficulty of chemistry learning viz; nature of the content, the method used to transact the content, lack of proper

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association of the content with prerequisites, and the nature of assessment in chemistry. This study intended to investigate the implications of Field-dependence/independence (FD/FI) and Working memory (WM) on achievement test design. The essential skills that chemistry learners are expected to develop through chemistry education such as understanding conventional representations, visualizing a spatial structure of a molecule from a symbolic or a two-dimensional (2D) representation, and relating properties of a matter with its molecular structure demands proper schema acquisition. (Dori and Barak 2001; Johnstone 1991; Treagust et al. 2003). But attainment of these skills are not taking place properly due to the particular nature of chemistry. Difficulties in learning chemistry has been explained with the Sweller's Cognitive Load Theory (1994).

The main concern of cognitive load theory is the requirement of adapting instruction to the constraints of the learner's cognitive system. Accordingly, working memory is "where" cognition occurs, the capacity of working memory is limited. Every student has a memory capacity at a specific age level. This working memory capacity has a significant role in their learning. Contemporary models define WM from different angles such as content, structure, function, or a combination of these dimensions (Miyake & Shah, 1999). Working memory constraints chemistry learning because understanding chemistry requires spatial ability, perception of abstract concepts and frequent complex calculations. Students, who lack these skills, find chemistry a difficult subject. According to Johnstone (1991), in the light of working memory's limited capacity, the novice learner in chemistry simply could not operate at microscopic, macroscopic and symbolic levels at the same time. Faced with new and often conceptually complex materials, the chemistry student requires to develop skills to organize the ideas so that the working space is not overloaded.

Cognitive Load Factors and Academic Performance

Cognitive load theory tries to integrate knowledge about the structure and functioning of the human cognitive system with principles of instructional design. It can be fruitfully applied to testing and assessment of learning too. Many traditional instructional and assessment techniques do not adequately take into account the limitations of the human cognitive architecture, as both instructional as well as testing situations unnecessarily overload the learner's working memory, the central "bottleneck" of cognitive system. Whatever one can do to reduce cognitive load advances learning and performance. While implication of cognitive load for instructional design has received much attention of researchers, the same cannot be said of the question regarding how cognitive load created in test and assessment situations affect student performance. Due to the importance of working memory in cognitive activities, performance, including on tests, involving cognitive tasks will be affected when information load exceeds individuals' working memory (Solaz Portolés, & Sanjosé López, 2009).

Field dependence/independence, like working memory, is a key dimension of cognitive performance. Witkin and Goodenough (1981) described a field-dependent individual as someone who has difficulty in separating an item from its context, whereas a field-independent individual is someone who can easily break up an organised field and separate relevant material from its context. Thus, the field-independent individual can distinguish between the signal and noise. Subjects with middle performance are called field-intermediate. The signal is that which is important for the task in hand while the noise is that which is not important for the task in hand. FI individuals can easily separate the most vital information from its context and are more likely to be influenced by internal rather than external prompts (Guisande et al. 2007). FD persons face difficulty in separating the information from its related background and are more likely to be influenced by external prompts. In addition, FI individuals have good analytic skills, (Saracho 2003).

Numerous studies have explored the relationship between field-dependence and academic performance (Onwumere, & Reid, 2014). Collectively, these studies suggest that, a) FD and FI individuals differ in the cognitive processes that they employ as well as in the effectiveness of their performance, b) FI students score significantly higher than FD students in almost every field of science and mathematics, c) FI people tend to be more 'self-sufficient' than FD people who tend to depend more on the external environment, d) Those who are more FI in ability tend to show a higher performance in tests measuring working memory capacity, e) FD individuals encounter difficulties in recalling encoded information unless retrieval cues are directly relevant to the way in which the information was coded. The relevant cues could be considered as 'bridge' to gain access to the stored information, f) FD individuals exhibit less efficient memory strategies than FI individuals when they encounter a problem. The explanation of the poor memory of FD individuals is that they process information in a rigid way which may be the result of an inefficient response to cues which would facilitate their recollection of the past information, and g) FI individuals are more capable of demonstrating cognitive structuring skills than FD individuals. Overall, the FI/FD dichotomy is a powerful instrument to predict academic performance of individuals (Terrell, 2002). No matter what the nature of assessment is, field-independent students perform better than field-dependent students (Tinajero and Paramo, 1998).

This study investigates whether the cognitive load factors (field independence, working memory) influence student performance in chemistry topics and whether these factors differentially affect student performance by the nature of items (level of complexity and level of visualization).

Cognitive Load in Chemistry Topics

In Chemistry, the Periodic Table is not only one of the basic organizing principles to which students are introduced (Schmidt et al., 2003), but also a central model used as a tool of induction (Ben-Zvi and Genut, 1998). Since the Periodic Table of the elements is a cornerstone for learning chemistry and a tool that serves to organize the whole of chemistry (Scerri, 2007), much research in chemistry education has concentrated on its different perspectives. Chemical bonding is considered by teachers, students, and chemical educators to be a very difficult and complicated concept (Gabel, 1996 &Taber, 2002). Since bonding is a central concept in 9th grade chemistry, a thorough appreciation of its nature and characteristics is essential for understanding almost every other topic in chemistry, such as carbon compounds, proteins, polymers, acids and bases, chemical thermodynamics, proteins, carbohydrates, and polymers (Nahum et al., 2004). Organic chemistry is a very important subject for all students of chemistry (Lin & Liu, 2003), a gateway course for secondary students. Rote learning of formulas and equations without proper conceptual understanding in organic chemistry creates working memory difficulties and in turn lead to cognitive load in students. Organic Chemistry is a field that relies upon the use of two-dimensional structures and figures to represent three-dimensional molecules. Students without field-independence find it difficult to comprehend organic chemistry in a meaningful way.

Influence of Field dependence/independence (FD/FI) and working memory on test performance

Mancy & Reid (2004) re-counted studies which revealed that working memory space and field dependency are useful predictors of success in conceptual areas such as mathematics and statistics. Those who performed best in all six school subjects including math and sciences tended to be those who are highly divergent and strongly visual-spatial as well as those tending to have higher working memory capacities and being more field independent (Hindal, Reid,& Whitehead, 2013). Likewise findings are reported in science too (Onyekuru, 2015). Working memory capacity may also be involved in a number of neo-Piagetian cognitive variables which work as predictors of achievement in science. There is an increase in students' information processing capacity with age (Pascual-Leone& Goodman, 1979). Another cognitive variable is the ability of a subject to dis-embed information in a variety of complex and potentially misleading instructional context; thus, the learners that have more difficulty than others in separating signal from noise are classed as field-dependent (Pascual-Leone, 1989). Studies on the association between limited working memory capacity and information load in problem-solving provided support for the positive relationship between working memory and science achievement. As working memory capacity limits the amount of information which can be concurrently processed, performance on science problem-solving tasks is expected to drop when the information load exceeds students' working memory capacity (Johnstone & El-Banna, 1986).

Danili and Reid (2004) found that students with high and low working memory capacity differed significantly in their performance on chemistry tests. Gathercole, (2005) found a strong relationship between working memory capacity and science achievement. The correlation coefficients between working memory measure and science achievement ranged from .32 to .5. Tsaparlis (2005) examined the correlation between working memory capacity and performance on chemistry problem-solving and the correlations ranged between .28 and .74.

Field dependence/independence and working memory affect the text book content, instruction and test situations in chemistry. Field independent person is not using up valuable working memory space with items which are not essential for the task in hand. This leaves more capacity available for understanding, and, hence, greater success (Johnstone, 1993). According to this study, students with a high working memory capacity and who are field-dependent are occupied with 'noise' as well as 'signal' because of the field dependent characteristic. Conversely, low capacity and field-independent students will receive only the 'signal', tending to ignore the 'noise', and they can use all their limited low working memory space for useful processing. Hence, high working memory capacity field dependent students cannot benefit from their larger working memory because the working memory capacity is effectively reduced by the presence of 'useless' information.

Solaz Portolés, and Sanjosé López, (2009) cites many studies indicating that students with better dis-embedding ability (i.e., field-independent students) are more successful solving problems than students with lower dis-embedding ability scores (i.e., field-dependent students). However Chandran et al. (1987) and by Robinson and Níaz (1991) have shown that this cognitive variable played no significant role in science achievement. Hence this study is on the effect of FD/FI and WM on test situation. It is hypothesised that the influence of working memory will be higher in the case of test items with multiple level or with complex diagrams and clear visual representation of test items will be favourable for field dependent students. Specifically, the question raised are; Do FI /FD influence performance in school chemistry? If yes, whether the influence of FI/FD is mediated by absence of visual representation in the items? Do WM influence performance in school chemistry? If yes, whether the influence of WM is mediated by the presence of less complex items?

Objectives

The major objective of the study is to investigate the association of test performance in chemistry topics with cognitive load factors (field independence, working memory) among secondary school students. The particular objectives of the study are: To find out the influence of type of item (with and without visual representation) on test performance in chemistry by the level of field independence among secondary school students; and to find out the influence of item complexity on test performance in chemistry by the level of working memory (high and low) among secondary school students.

Methodology

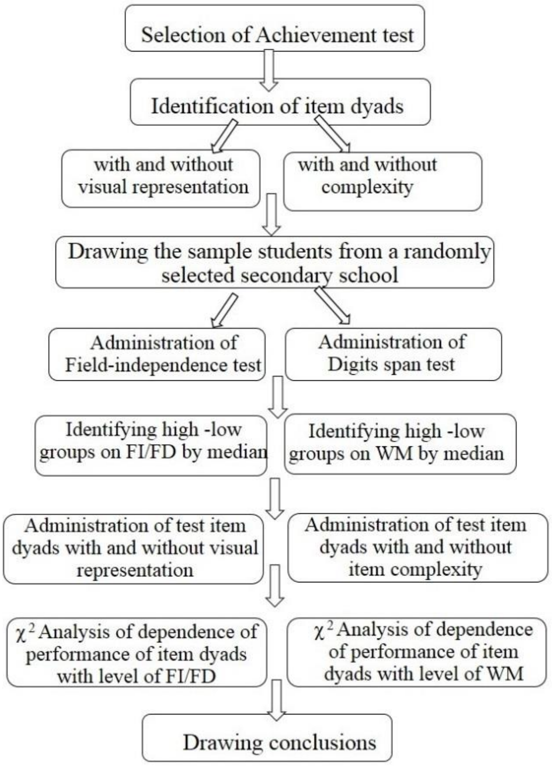
The influence of field independence on five dyads of test items with and without visual representation (to assist FDs) and the influence of working memory on five dyads of test items with and without complexity (in terms of item structure and presentation involving noise) were considered. The ten items were covering ten minor concepts in Periodic table, Chemical bonding and Organic chemistry. The concepts Periodic table, Chemical bonding and Organic chemistry are found to be the most difficult concepts in secondary school chemistry (Gafoor & Shilna, 2014). Analysis of the influence of field independence and working memory was done by making these ten items into pair by comparing each of the item with a parallel item. The influence of FD/FI and working memory on chemistry achievement was analysed by making students into two groups based on two levels (high and low) of FD/FI and working memory.

Sample of the study

The sample consists of 96 standard IX students, both males and females, from a randomly selected secondary school in Kerala.

Design of the study

The design of the study is showed in a flow chart



Tools used for the study

An Achievement Test in Periodic table – Chemical bonding and Achievement test in Organic chemistry (Gafoor & Shilna, 2014) is used. Ten item dyads of with and without visual representation and with and without complexity were selected. Example of the two set of dyads are given in figure 1a and 1b.

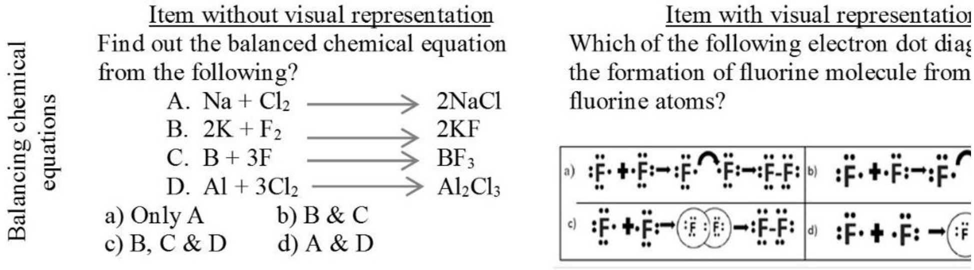


Figure 1a. Illustration of item dyad with and without visual representation

Arrangement of elements in Periodic table	Complex item	Simple item
	To make the above table of elements in to a periodic table some changes are listed below. Which is right? A. Write atomic numbers B. Write electronic configuration C. Write metals, metalloids, non-metals D. Write the symbols a) A is right b) A & B are right c) A, B and C are rightd) B, C and D are right	While writing the configuration of four ele (2, 8, 2), (2, 8, 5), (2, 8, 7) Rahul identified an odd you say which that odd on a) 2, 8, 2 b) 2, 8, 5 c) 2, 8, 7 d) 2, 8, 8

Figure 1b. Illustration of item dyad with and without complexity

In addition to the two sets of item dyads, the field independence and working memory capacity of the students were measured using Digits Span test (Wechsler, 1949) and Field independence testing (OkCupid, 2014).

Results and Discussion.

1. Influence of the Level of Field independence in Chemistry

Right and wrong response patterns of students by the level of Field independence (high and Low) with results of χ 2 tests are given in Table 1. Five minor concepts viz; Balancing chemical equations, Attaining stability, Covalent bonding, Valency of carbon, and Molecular formula of organic compounds, were considered. Two types of items with and without visualization under one particular minor concept were taken into consideration.

Table 1

Data and Results of χ^2 tests on Response patterns (Right and Wrong) on Items with and without Visual Representation by the Level of Field independence (high and Low)

Sl No:	Minor concepts	Types of items	Level of FI	Response		χ^2	sig
				Right	Wrong		
1	Balancing chemical equations	Without visualization	High FI	33	18	4.87	.02
			Low FI	19	26		
		With visualization	High FI	33	18	1.82	.22
			Low FI	23	22		
2	Attaining stability	Without visualization	High FI	35	16	5.71	.01
			Low FI	20	25		
		With visualization	High FI	31	20	0.91	.41
			Low FI	23	22		
3	Covalent bonding	Without visualization	High FI	41	10	3.90	.04
			Low FI	28	17		
		With visualization	High FI	35	16	1.22	.29
			Low FI	26	19		
4	Valency of carbon	Without visualization	High FI	32	19	4.04	.03
			Low FI	19	26		
		With visualization	High FI	40	11	0.68	.48
			Low FI	32	13		
5	Molecular formula of organic compounds	Without visualization	High FI	37	14	6.69	.01
			Low FI	21	24		
		With visualization	High FI	32	19	0.07	.83
			Low FI	27	18		

Table 1 shows that items with visual representation helps the students with low field independence to comprehend the item easily. Item with visual representation under any of the minor concepts, shows that students with low field independence can score the item at par with the students with high filed independence. Here the provision of visual representation helps the students to overcome the difficulty level of the item.

2. Influence of the Level of Working memory in Chemistry

Right and wrong response patterns of students by the level of Working memory (high and Low) with the results of χ 2 tests are given in Table 2. Five minor concepts viz; Arrangement of elements in Periodic table, Properties of Periodic table, Classification of elements before Periodic table, Ionic compounds, and Classification of hydrocarbon based on structure were considered. Two types of items with and without complexity under one particular minor concept were taken into consideration.

Table 2
Data and Results of χ² tests on Response patterns (Right and Wrong) on Items with and without Complexity (Complex and Simple) by the Level of Field independence (high and Low)

Sl No:	Minor concepts	Complexity of items	Level of WM	Response		χ^2	sig
				Right	Wrong		
1	Arrangement of elements in Periodic table	Complex	High WM	32	14	3.80	.04
			Low WM	25	25		
		Simple	High WM	33	13	1.46	.22
			Low WM	30	20		
2	Properties of Periodic table	Complex	High WM	34	12	3.36	.05
			Low WM	28	22		
		Simple	High WM	26	20	0.56	.45
			Low WM	32	18		
3	Classification of elements before Periodic table	Complex	High WM	29	17	2.80	.05
			Low WM	23	27		
		Simple	High WM	30	16	0.85	.35
			Low WM	28	22		
4	Ionic compounds	Complex	High WM	35	11	3.52	.04
			Low WM	29	21		
		Simple	High WM	32	14	0.61	.52
			Low WM	31	19		
5	Classification of hydrocarbon based on structure	Complex	High WM	26	20	3.30	.05
			Low WM	19	31		
		Simple	High WM	31	15	0.02	.88
			Low WM	33	17		

Table 2 shows that items with less complexity helps the students with low working memory to understand the item easily. Item with visual representation or multiple levels of options increase the complexity of the item which creates difficulty in even comprehending the item for a student with low working memory capacity. However, for an item with relatively simple format, under any of the minor concepts the students with low working memory can score the item at par with the students with high working memory. The provision of complex item makes the students to feel it as ambiguous.

The results also reveals that a less difficult item without visual representation do not favor the low field independent student and similarly a less difficult item with complex format do not favor the the students with low working memory. This means that an item seems to be difficult depending up on the way it is presented more than up on the difficulty level of the content and concept involved.

Conclusion

The study implies the need for redesigning test materials to reduce the amount of information students had to deal with simultaneously. The interpretations are listed as follows.

1. The items with verbal, numerical and visual explanation helps students with low field independence but the same items with multiple levels and complex diagrams do not support the students with low working memory.
2. Multiple cognitive tasks in a single item may be avoided as they are found to be inappropriate for students with low working memory. The items may focus on the concept involved instead of item format.
3. The attempt to reduce the complexity of an item by reducing its visual portrayal adversely affects the students with low field independence. Conversely attempt to reduce the field dependence of the students by incorporating diagrammatic explanation which makes the item complexly structured, it adversely affects students with low working memory.
4. It will be difficult for a student with low working memory to attempt the item with multiple levels, such as the item presented with data and figure, the item with more than two concepts in chemistry.
5. The achievement test should be constructed based on the objectives, content, concepts, principles and the like relevant to chemistry. Relatively complex items actually do not measure the relevant area, because such items require complex multiple cognitive tasks less relevant for the chemistry. While constructing items, measures to decrease external cognitive load like dialogue boxes, pictures, diagrams, and models should focus on on the main task rather than task irrelevant details.

Working memory overload occurs when there is too much information or too many manipulations are required simultaneously. Johnstone and Wham (1982) suggested that working memory overload appears to occur when the learner cannot differentiate the “message” or important information from the “noise”; the non-essential and often irrelevant information that the teacher is transmitting to the learners. The field independent person is capable of using his or her working memory space more efficiently simply because it is not becoming cluttered with information irrelevant to the problem being faced. Teachers can decrease external cognitive load by presenting the materials in a way that is easy to understand or by lessening internal cognitive load through reducing the interactivity among elements (Miyake, & Shah, 1999) in the achievement test items. Redesigning test-items that split students’ attention, for instance from a text paragraph and a separate diagram to an integrated diagram or verbal explanation only may help reduce external cognitive load in test situations.

If extent of field dependency is a critical skill in enabling success, the goal must be to see if it can be taught in some systematic way. This will reduce cognitive load on the working memory and lead to higher attainment. In particular, there may be very large benefits for those whose working memory capacities happen, by chance of genetics, to be less than average (Onwumere, & Reid, 2014). Cheung (2009) observed that the difficulty of an item should not be increased by incorporating more complicated information in the stem. Including complex multiple choice items in order to make the question harder should be avoided.

The results may be interpreted in a way that the students with low field independence cannot handle the item without visual representation, the same students can better switch similar items presented with visual representation. Similarly in the case of students with low working memory, the items intended to measure the content knowledge with multiple level of options are seems to be complex and they do not measure the content knowledge; instead they measure some other higher tasks which actually not an objective of the achievement test in chemistry.

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