Field Dependency and Performance in Mathematics

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Mathematics is an important school subject but one which often poses problems for learners. It has been found that learners do not possess the cognitive capacity to handle understanding procedures, representations, concepts, and applications at the same time. while the extent of field dependency may hold the key to one way by which the working memory can be used more efficiently. This study aims to explore the concept of field dependency which may offer a way forward in reducing the cognitive demands of finite working memory capacity, thus enabling higher performance to be attained. Age and gender were considered. With a sample of 120 secondary school students, the importance of working memory in relation to mathematics performance was confirmed (r = 0.55). The extent of field dependency was measured with a larger sample of 547, drawn from five age groups. The outcomes were related to the performance in mathematics examinations, a correlation of 0.32 being obtained overall, with every age group showing positive significant correlations. In this, the more field independent perform much better. The outcomes are interpreted in terms of the increased efficiency in the use of finite working memory capacity resources. It was found that students become more field independent with age but the rate of growth of independence declines with age. Girls tended to be slightly more field-independent than boys, perhaps reflecting maturity or their greater commitment during their years of adolescence. The findings are interpreted in terms of the way the brain processes information and the implications for mathematics education are discussed briefly.

Keywords: field dependency, working memory, mathematics education

Introduction

Mathematics is well-known as a school subject which can cause learners considerable difficulty. The aim of this study is to confirm that limited working memory capacity is one key factor explaining this difficulty and to explore the concept of field dependency which may offer a way forward in reducing the cognitive demands of finite working memory capacity, thus enabling higher performance to be attained.

The Field Dependency Characteristic

Witkin and Asch (1948) found that some individuals show remarkable consistency to different types of cues. This led to the development of the concept of field dependency and ways to measure its extent (Witkin, 1964; Witkin et al., 1962, 1971, 1974, 1977; Witkin & Goodenough, 1981).
Jonassen and Grabowski (1993) noted that field dependency describes the extent to which:

“• The surrounding framework dominates the perception of items within it.
• The surrounding organised field influences a person’s perception of items within it.

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• A person perceives part of the field as a discrete form.
• The organisation of the prevailing field determines the perception of its components, or
• A person perceives analytically."

Jonassen and Grabowski, (1993, Page 87)

This is fairly complex picture of field dependency. By contrast, 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.

Research led by Witkin and Asch (1948) focused initially on perception, as they identified differences in individuals who were deciding whether an object was upright in space. Research into field dependency led to an awareness that competence at disembedding shapes and objects was strongly associated with competence at disembedding in other non-perceptual, problem solving tasks. This resulted in the construct being broadened to encompass both perceptual and intellectual activities and was referred to as the global-articulated dimension. Later, with additional evidence on self-consistency, extending to the areas of body concept, sense of self, and controls and defences, the construct became even more comprehensive and was labelled as 'psychological differentiation' (Witkin et al., 1962; Witkin, 1964; Witkin and Goodenough, 1981).

Ghani (2004) and Chu (2007) have brought together the findings of many studies and noted factors that influence the extent or degree to which a learner is either field-dependent or field-independent. Some of these factors are:

(i) Age: Children are generally field-dependent, but their field-independence increases as they grow older to become adults (Gurley, 1984). After that time, the field-independence gradually decreases throughout the remainder of life, with the older tending to be more field-dependent than their younger cohorts (Witkins et al., 1971).

(ii) Gender: Studies found that males perform slightly better in the hidden figure tests (tests of field-dependent/field-independent) but the gender effect is so small that this factor is practically insignificant (Musser, 1998).

(iii) Childhood Upbringing: Children from families where there is encouragement for them to develop separate, autonomous functions are relatively field-independent, while others who showed emphasis to parental authority and guidance are likely to become relatively field-dependent (Korchin, 1986). This list of factors is very revealing. It suggests that extent of field dependency is open to development by means of experiences and, perhaps, formal learning.

Field Dependency and Academic Achievement

Danili and Reid (2004) note the huge number of studies on field dependency. Tinajero and Paramo (1998) concluded that 'in general, field-independent subjects perform better than field-dependent subjects, whether assessment is of specific disciplines or across the board'. This is well supported in the sciences (Johnstone & El-Banna, 1986, 1989; Bahar & Hansell, 2000; Danili & Reid, 2004).

The key thing to note is that the 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). In mathematics, Al-Enezi (2008) found a strong correlation of extent of field dependency with performance in mathematics tests. Indeed, she went further to show, using factor analytic techniques, how the field dependency variable loaded on to the same factor as mathematics performance, causing her to ask, 'Is ability to select information from noise the same as skill in mathematics?' (page 192).

The investigation carried out by El-Banna (1987) on the relationship between performance in chemistry examinations of low, medium, and high memory capacity students related to field-dependency shows that among students with the same working memory capacity, the performance declines when the student is more field-dependent. A possible explanation of these results could be the fact that "students with low working memory capacity are not in position to devote any working space to the irrelevant information, and consequently field-independent low working memory capacity students would possibly perform better than the field-dependent low working memory capacity students" (Johnstone and Al-Naeme, 1991).

In a study carried out by Christou (2001), he found little difference in performance in exploring algebra story problems between low working memory capacity field-independent students and high working memory capacity field-dependent students. His results are shown in Table 1.

Table 1. Mean Mathematics Performance, Working Memory Capacity, Extent of Field Dependency

N = 90	Mean Mathematics Scores (%)		
Group	Field Dependent	Field Intermediate	Field Independent
Working Memory Capacity = 4	50	61	78
Working Memory Capacity = 5	59	73	83
Working Memory Capacity = 6	73	73	84

Similarly, Al-Enezi (2008) found the same pattern of outcomes with a very much larger sample (table 2).

Table 2. Mean Mathematics Performance, Working Memory Capacity, Extent of Field Dependency

N = 874	Mean Mathematics Scores (%)		
Group	Field Dependent	Field Intermediate	Field Independent
Working Memory Capacity = 4	59	64	70
Working Memory Capacity = 5	60	68	77
Working Memory Capacity = 6	65	73	77

The findings of Christou and Al-Enezi are completely consistent with the previous findings in chemistry (Johnstone and Al-Naeme, 1991; Danili and Reid, 2004, 2006).

A possible explanation of these results can be obtained using suggestions made by Johnstone et al., (1993). According to them, students with a high working memory space 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.

Numerous studies have explored the relationship between field-dependence and academic performance (Goodenough, 1976; Witkin et al., 1977; El-Banna, 1987; Johnstone and Al-Naeme, 1991; Uz-Zaman, 1996; and Danili, 2001. Together, these studies suggest that:

- Field-dependent and field-independent individuals differ in the cognitive processes that they employ as well as in the effectiveness of their performance.
- Field-independents score significantly higher than field-dependents in almost every field of science and mathematics.
- Field-independent people tend to be more ‘self-sufficient’ than field-dependent people who tend to depend more on the external environment.
- Those who are more field-independent in ability tend to show a higher performance in tests measuring working memory capacity.
- Field-dependent 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.
- Field-dependent individuals exhibit less efficient memory strategies than field-independent individuals when they encounter a problem. The explanation of the poor memory of field-dependent 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.
- Field-independent individuals are more capable of demonstrating cognitive structuring skills than field-dependent individuals.

Assessment of Field Dependency

The early work on the measurement of field dependency was carried out with the use of the first Body Adjustment Test with an attempt to replicate those conditions experienced by pilots in fighter aircraft flying through low cloud formation. The early version of the test involved the person being seated on a tilted chair, in a tilted room, and being asked to adjust the body to the upright. A further version of the test, called the Rod and Frame Test, involved the individual being seated in a completely darkened room. The person was asked to view a tilted luminous rod, within a tilted luminous frame. However, the individual was then asked to disregard the frame, and adjust the rod until it was in a totally upright position. Interest was focused on the relationship between a person’s visual and kinaesthetic abilities, and the levels of dependence on the visual context displayed.

As the implications of the concept of field dependency became more apparent, a paper and pencil assessment was developed reflecting earlier work on the discrimination of shape from its surrounding field carried out by Thurstone (1944). This was later developed into the Group Embedded Figure Test (GEFT) (Witkin et al., 1971, 1977). When many shapes are identified correctly, the person is described as field-independent; when few shapes are identified correctly, the person is described as field-dependent. A form of this test, known as the Hidden Figures Test, was used in the present study in order to obtain data from a group of students about how they learn process and retrieve information.

Field Dependency and Mathematics

Mathematics is well known as being considered a ‘difficult’ subject. Long ago, Sawer (1959) saw abstraction as a process of forgetting unimportant details and argued that, without abstraction, thought would be impossible. The work of Piaget (1963) has established the learner as a person who is trying to make sense of what is experienced. In looking at 'making sense of', the problem is that this will often generate working memory overload and yet it is this dimension which is the natural way of learning and understanding.

Ali and Reid (2012) have reviewed areas of difficulty in mathematics, relating these to working memory overload, and have shown, with large samples, that those with above average working memory capacities have enormous advantages over those with below average working memory capacities. They introduced the mathematics tetrahedron which illustrates the problem (figure 1), based on the widely-quoted triangle model of Johnstone (1991).

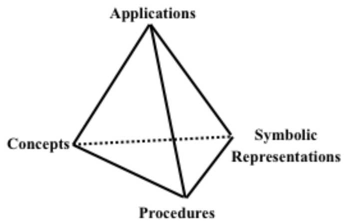


Figure 1. The Mathematics Tetrahedron (Ali and Reid, 2012)

The point they are making is that, in mathematics, 'trying to master the processes and symbolism may well create enough pressure on limited working memory capacity. The learner cannot cope with concepts (understandings), procedures, symbolisms and applications all at the same time' (Ali and Reid, 2012: 284).

That is where field dependency may be so important. Those who can select in only what is essential for the task in hand (the more field independent) will be less likely to face working memory overload. If the 'skill' of being field independent can be developed, encouraged or taught, then we are giving to learners a means by which performance in a subject like mathematics can be improved

Experimental Methodology

Measurement of Working Memory Capacity

Two tests have been described and are widely used (Reid, 2009). In the Figural Intersection Test (FIT), candidates are asked to shade in the common area of overlap of an increasing number of geometrical shapes. In the Digit Span Backward Test (DSBT), increasing numbers of numbers are read out to candidates who then have to write them down in reverse order. The tests are described in detail in Chen and Whitehead (2009), and Danili and Reid (2004), respectively. In one study, both tests were used with the same candidates, giving identical outcomes for the vast majority and differing only by one unit for most of the remainder (Elbanna, 1987, page 62, discussed in Reid, 2009). Thus, validity and reliability are assured. Reid (2009) has listed a number of studies in various subject areas and the table from that paper is given here along with data from some studies in mathematics. This is shown, slightly updated, in table 3.

The digit span backwards test was used here and the size of the working memory capacity was taken as the highest number of digits that a student was able to recall correctly. The results of the working memory capacity test were correlated with the examination scores in mathematics for the senior secondary students. Correlation only shows if two variables are associated. It does not indicate causality. However, the key experiments of Johnstone and El-Banna (1986, 1989) show that the relationship is, indeed, causality. Previous work had, therefore, indicated that limited working memory capacity was one factor which influenced success in mathematics examinations.

In order to confirm that working memory space influences performance in mathematics, students examination marks were correlated with their scores from the digit span backwards test. Table 4 shows the correlation of students' mathematics examination marks with working memory capacity for senior secondary students only.

Table 3. Summary of Some Data

Age	Country	Sample	Subject	Test Used	Pearson Correlation	Probability	Source
13-15	India	454	Science	DSBT	0.34	p < 0.001	Prasad, 2005
13	Kuwait	641	Science	FIT	0.23	p < 0.001	Hindal et al, 2013
15	Greece	105	Chemistry	FIT	0.34	p < 0.001	Danili and Reid, 2004
13	Taiwan	151	Physics	FIT	0.30	p < 0.001	Chen and Whitehead 2009
13	Taiwan	141	Biology	FIT	0.25	p < 0.001	Chu and Reid, 2012
13	Taiwan	141	Genetics	FIT	0.62	p < 0.001	Chu and Reid, 2012
16-17	The Emirates	809	Physics	DSBT	0.11	p < 0.01	Al-Ahmadi and Oraif, 2009,
16-17	The Emirates	349	Physics	DSBT	0.32	p < 0.001	Al-Ahmadi and Oraif, 2009,
12-15	Saudi Arabia	120	Sciences	FIT	0.30-0.49	p < 0.001	Al-Osaimi et al., 2013
16	Greece	90	Mathematics	DSBT	0.40	p < 0.001	Christou, 2000
14-15	Kuwait	874	Mathematics	DSBT	0.52	p < 0.001	Al-Enezi, 2004
14-15	Kuwait	472	Mathematics	DSBT	0.24	p < 0.001	Al-Enezi, 2008
14-15	Kuwait	874	Mathematics	DSBT	0.36	p < 0.001	Al-Enezi, 2008
10	Pakistan (Urdu)	150	Mathematics	FIT	0.69	p < 0.001	Ali and Reid, 2012
10	Pakistan (English)	150	Mathematics	FIT	0.43	p < 0.001	Ali and Reid, 2012

Table 4. Working Memory Correlation

Sample	Exam Data		Digit-Span Backwards Test		Pearson Correlation	
	Mean	Standard Deviation	Mean	Standard Deviation	r	p
N = 120	61.5	13.4	5.7	1.6	0.55	< 0.001

The mean outcome from the digit span backwards test is approximately what might be expected for students aged about 16. It can be seen that there is a positive relationship between students' working memory capacity and mathematics achievement. Indeed, a value of 0.55 is quite high, indicating that over 30% [0.55^2, as %] of the variance of the mathematics performance was being caused by the working memory capacity.

The sample of 120 was divided into three groups. Approximately, one third of the population will lie below one half of one standard deviation below the mean, while approximately, one third of the population will lie above one half of one standard deviation below the mean. By using division points at half of one standard deviation above and below, three approximately equal groups will be obtained. This approach has been widely used, the first uses being by Case (1974) and Scardamalia (1977).

The effect on examination performance is large and is illustrated in Table 5. The difference in performance between the average in the lower working memory capacity group and the upper working memory capacity group is nearly 17%. This difference might be caused during the learning process or might simply reflect the types of questions asked in this particular examination, or both.

Table 5. Marks and Working Memory Capacity

Working Memory Capacity	Number of Students	Average Examination Mark (%)
Above average	42	67.2
Average	45	64.3
Below average	33	50.3

Field Dependency

Working memory capacity is fixed genetically (Miller, 1956). However, the capacity a learner possesses may be used more efficiently. One of the main ways by which limited capacity is used more efficiently is by means of what Miller called 'chunking'. Ideas or units of information can be grouped together in that they are seen as one 'chunk'. Less space in the working memory, therefore, is used, leaving more space for processing or handling other ideas. Another way by which the limited capacity of working memory can be used more efficiently is by avoiding information that is not essential for the task in hand. The concept of field dependency helps here.

The field-independent learner is capable of selecting in only that which is essential for the task in hand. This means that the working memory is less likely to overload. Field dependency could be genetic in origin, a learned characteristic or a characteristic adopted by some element of choice (Figure 2). Of course, the development of this characteristic may arise from any combination of these three factors.

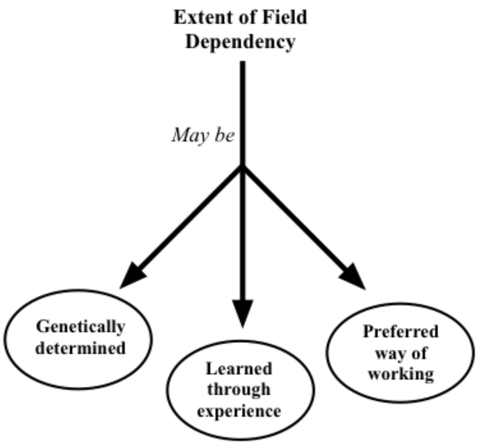


Figure 2. Nature of Field Dependency

The key issue is this. The limitations of working memory capacity constitute one key factor in success in mathematics assessments. However, working memory capacity is fixed for an individual. To improve performance, the assessments may need to be changed so that those with higher working memory capacities do not have the advantage and Reid (2002) has shown that this is possible. Alternatively, steps need to be taken to develop ways by which the limited working memory capacity can be used more efficiently. Field dependency may offer assistance here, but only if this characteristic can be developed in some practical and acceptable way. Thus, if the skill of being field independent is open to development by means of experiences in the learning situation, then it becomes an interestingly possible that such experiences might be integrated into normal school programmes, thus raising the prospect of improved examination performance.

A sample of 547 students was now drawn randomly from a range of schools across five age groups. Table 6 shows the details of the samples, which were drawn from schools serving a diversity of areas and social backgrounds.

Table 6. Students' Sample Sizes

Year Group	Approximate Age	Boys	Girls	Total
Year 7	13	43	49	92
Year 8	14	85	83	168
Year 9	15	52	50	102
Year 10	16	79	63	142
Year 11	17	20	23	43
Totals		279	268	547

The Hidden Figure Test was used to measure the extent of field dependency of all 547 students. The relationship between extent of field dependency and performance in mathematics was explored using Pearson correlation. It is also possible to illustrate any relationship by dividing the sample into three groups (field-dependent, field-independent, field-intermediate), using half-standard deviation method.

In every task, the students were asked to recognise and identify a simple geometric shape in a complex figure, by tracing its outline with a pen or pencil against the lines of the complex complex figure. The whole test consists of 20 tasks and 20 minutes was allowed. Thus, the possible maximum score that can be obtained is 20. Sample items from the test are shown in the Appendix. The main scoring scheme for the tests is to give one point for a correct simple shape embedded in a complex figure.

Three questions were explored:

(1) Are there significant relationships between field-dependence and mathematics performance?

(2) Does field dependency grow with age?

(3) Are there any gender differences related to field dependency?

Examination marks for each year group were obtained. The marks reflected the work of the previous year covering the same curriculum in all three schools for each year group. Marks were standardised for each year group (mean 50, standard deviation 12). The extent of field dependency was measured for each of the 547 students.

The data gave approximately normal distributions, with the following parameters (table 7).

Table 7. Data Distributions

Measurement (N = 547)	Mean	Standard Deviation
Mathematics Marks (standardized)	50.0	12.0
Extent of Field Dependency	10.1	5.11

The correlations obtained by relating performance in mathematics to the measure extent of field dependency are shown in table 8.

Table 8. Field Dependency and Performance in Mathematics

Pearson Correlation: Field Dependency and Mathematics Scores			
Age	Sample Size	r	p
13	92	0.54	< 0.001
14	168	0.22	< 0.01
15	102	0.52	< 0.001
16	142	0.25	< 0.01
17	43	0.44	< 0.01
Total	547	0.32	< 0.001

The variations in correlation will reflect the actual examination papers set, the way the questions were asked and the topics being tested. Thus, it is possible to set questions where the student has no problem in seeing what is important or what has to be done first. Equally, it is possible to set questions where the skill of being able to see what is important or what has to be done first are important.

It is possible to look at the entire sample. The overall correlation of mathematics marks (standardised) and extent of field dependency is 0.32 ($p < 0.001$), in line with the findings of Al-Enezi (2008). Thus, if the standardised mathematics marks reflect some kind of general ability in mathematics, then this ability correlates with the measured extent of field dependency. The power of the relationship can be illustrated by dividing the entire sample into three groups (table 9).

Table 9. Classification of sample

Group	Number of students	Field Dependency Score Range	Mean Mark in Mathematics
Field Dependent	191	0-7	45.6
Field Intermediate	177	8-12	50.9
Field Independent	179	13-20	53.5
Total	547		

Field Dependency and Age

The outcomes for the whole sample were analysed using ANOVA to see if the measured extent of field dependency changes significantly with age (Table 10). The findings show that there is a significant growth of field dependency with age (Table 10).

Table 10. Field Dependency and Age

Age	Sample Size	Mean FD Score	Standard Deviation	Analysis of Variance	
				F	p
13	92	6.9	3.4		
14	168	9.6	4.7		
15	102	10.6	5.2	17.6	< 0.001
16	142	11.8	5.3		
17	43	12.3	5.2		

In looking at the data in table 10, it is possible that the extent of field dependency changes with age, simply on the basis of cognitive development, in parallel with the growth in working memory capacity with age (Miller, 1956). Alternatively, the measured growth with age may be a reflection of learning or more general life experiences. If this is so, then is it possible (and easy) to encourage the development of this learner characteristic by specific teaching strategies?

Thus, Ausubel (1968) found that what a learner already knew was absolutely critical in influencing success at the next stage of learning. This finding is reflected in the Johnstone Information Processing Model (Johnstone, 1997) in what he called a 'feedback loop'. Knowledge held in long-term memory was influencing the the way information is selected. It is possible that this is a key feature of what is meant by field dependency. The long-term memory is enabling the filter to work more efficiently in the more field-independent person: previous knowledge and experience allows a more efficient selection, thus reducing the load on working memory.

It is possible to show the growth in field independency with age as a graph (Figure 3)

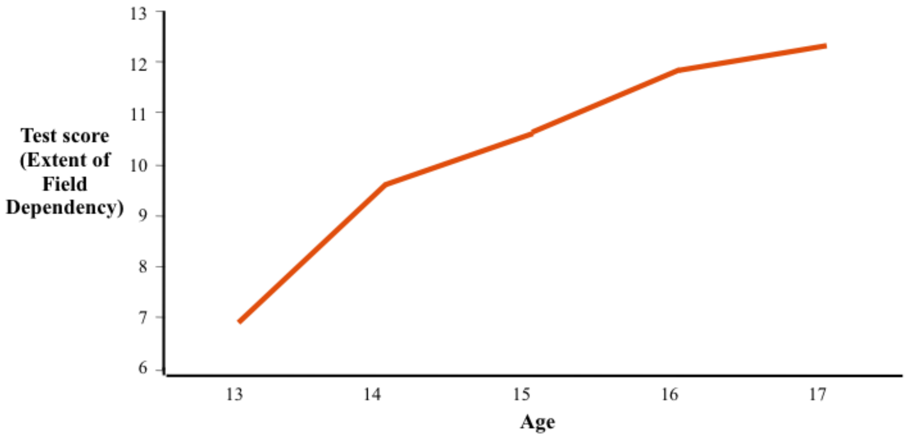


Figure 3. Extent of Field Dependency and Age

From the Figure 2, it is interesting to see that extent of field dependency increases with age. However, the graph suggests that the rate of growth declines with age. Although the growth may simply reflect cognitive development, essentially genetic in nature, it seems intrinsically more likely that the growth is predominantly brought about by learning and experience (Witkins et al., 1971; Gurley, 1984). If the rate of growth is most marked at younger ages, then this is where the effort needs to be expended to enhance the skill of being field independent.

Gender Issues and Field Dependency

It has been observed by Ali (Ali, 2008; Ali and Reid, 2012) that there are many gender differences in terms of students' overall cognitive structure, perception and understanding of mathematics. On one hand, girls seem to dominate in understanding and general commitment and, on the other hand, boys tend to dominate in terms of perception and showing strong relationships. In the present study, the overall field dependency measurements were divided by gender and the results are shown in Table 11.

It is surprising and very interesting to note that the girls tend to be more field independent than the boys (contrary to what Musser, 1998, found). Gender differences in field dependency may derive from basic physiological differences, such as in the ability to hear, perceive and process information, and also from differences in innate potential. This occurrence of gender interactions needs more careful study since these suggest a possible fundamental gender difference in information processing and, if these were better understood then both genders might be helped to learn more effectively. However, the explanation might simply lie in cognitive development where girls at these ages are often markedly more mature than boys. This may lead to a greater attention to detail, to study and greater commitment to look for what is right. However, there may well be cultural factors involved here, explaining the discrepancy between the findings of Musser (1998) and what was found here.

Table 11. Gender and Field Dependency

	Descriptive Statistics for Field Dependency Measurements						
	Sample	Maximum	Minimum	Mean	Standard Deviation	t	p
Boys	279	20	0	9.6	4.9	2.5	< 0.01
Girls	268	20	0	10.7	5.2		
Total	547	20	0	11.2	5.1		

Summary

The Group Embedded Figure Test (Witkin et al. 1971) is well established as a valid and reliable test of extent of field dependency. The test is non-verbal in nature and requires only a minimum level of language skill for performing the tasks (Cakan, 2003) while the psychometrical properties of the instrument have been investigated in cross-cultural settings and accepted as quite reasonable. The version used here (the Hidden Figures Test) is essentially the same, but with different shapes and a slightly shorter length for school students.

Field dependency may be determined by an individual's genetic origin, a learned characteristic as a result of experience, or as a characteristic adopted by some element of choice. It may involve all three. The fact that extent of field dependency grows with age does not necessarily show that it is experience related. Working memory is known to be genetic in nature and it grows with age. However, it does seem likely that experience is a factor in the development of field dependency (strictly, in the increase in extent of field independence). Teachers do encourage their students, especially in subjects like mathematics, to focus in on the key information. This suggests that their experience shows that this tactic brings benefits to the student, thus implying some kind of learning of field dependency.

The importance of field dependency is that development of this skill may be powerful in reducing the demands on limited cognitive resources in working memory, thus enabling the working memory to operate more efficiently and effectively. This has considerable potential in enhancing understanding in mathematics as well as enabling improved performance in mathematical tasks.

Overall, the following results were obtained as a result of data analysis:

(1) There is a significant relationship between field dependency and achievement: field-independent students had better performance than field-dependent students for all five age groups.

(2) Field independency increases with age: there are several possible reasons for this although it is highly likely that formal learning and life experiences may enhance the field dependency skill.

(3) Girls tend to be more field-independent than the boys: it is difficult to explain this but there may be developmental or cultural reasons.

Implications

Success in mathematics means, among other things, being skilled at being able to solve problems that are essentially mathematical in nature. One of the common complaints of school students, as mathematics teachers know, is that the learners state that they do not know where to start. The skill in being able to focus in on the essential information that is key in solving a mathematical problem is clear. Indeed, many teachers of mathematics are highly skilled in being able to direct their students to focus in what is important - this is essentially what being field independent enables the learner to do.

If extent of field dependency is a critical skill in enabling success in mathematics, 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.

References

Al-Ahmadi, F and Oraif, F. (2009). Working memory capacity, confidence and scientific thinking. *Research in Science and Technological Education*, 27(2), 225-243.

Al-Enezi, D. (2008). Difficulties Associated with Teaching and Learning Mathematics: A Study of Psychological Factors Affecting Pupils' Performance. PhD thesis, Glasgow: University of Glasgow. Retrieved from: thesis.gla.ac.uk/333/

Ali, A. A. (2008). Perceptions, Difficulties and Working Memory Capacity Related to Mathematics Performance. MSc thesis, Glasgow: University of Glasgow. Retrieved from: http://theses.gla.ac.uk/441/

Ali, A.A. and Reid, N. (2012). Understanding Mathematics Some Key Factors. *European Journal of Educational Research*, 1(3), 283-299.

Alosaimi, K.H., Reid, N and Rodrigues, S. (2014). Critical Thinking - Can it be measured ? Journal of Science Education, 15(3), 30-36.

Ausubel, D. P. (1968). Educational Psychology: a Cognitive View. New York: Holt, Rinehart and Winston.

Bahar and Hansell (2000). The Relationship Between Some Psychological Factors and their Effect on the Performance of Grid Questions and Word Association Tests. *Educational Psychology*, 20(3), 349-364.

Cakan, M. (2003). Psychometric Data on the Group Embedded Figure Tests for Turkish Undergraduate Students. *Perceptual and Motor Skills*, 96, 993-1004.

Case, R. (1974). Structures and Structures, Some Functional Limitations on the Course of Cognitive Growth. Cognitive Psychology, 6, 544-574.

Chen and Whitehead, (2009). Understanding physics in relation to working memory, *Research in Science and Technological Education*. 27(2), 151-160.

Christou, K. (2001). Difficulties in Solving Algebra Story Problems with Secondary Pupils. MSc Thesis, Glasgow: University of Glasgow.

Chu, Y-C and Reid, N. (2012). Genetics at school level: addressing the difficulties, *Research in Science and Technological Education*, 31(1), 1-25.

Chu, Y. C. (2007). Learning difficulties in Genetics and the Development of Related Attitudes in Taiwanese Junior High Schools, PhD Thesis, Glasgow: University of Glasgow. Retrieved from: http://theses.gla.ac.uk/168/

Danili, E. (2001). New Teaching Materials for Secondary School Chemistry: A Study of Psychological factors Affecting Pupil Performance. MSc Thesis, Glasgow: University of Glasgow.

Danili, E. and Reid, N. (2004). Some Strategies to Improve Performance in School Chemistry Based on two Cognitive Factors. Research in Science and Technological Education, 22(2), 203-226.

Danili, E. and Reid, N. (2006). Some potential factors affecting pupils' performance, *Chemistry Education Research and Practice*,7(2). 64-83.

El-Banna, H. (1987). The Development of a Predictive Theory of Science Education Based upon Information Processing Theory. PhD Thesis, Glasgow: University of Glasgow.

Ghani, S. A. (2004). Attitudes, Performance, and Psychological Characteristics of Student Teachers Learning Introductory Statistics. PhD Thesis, Glasgow: University of Glasgow.

Goodenough, D.R. (1976). The role of individual differences in field dependence as a factor in learning and memory. *Psychological Bulletin*, 83(4), 675-694.

Gurley, M. P. (1984). Characteristics of Motivation, Field-independence, Personality Type, Learning Style and Teaching Preference of the Adult Learner as Compared with Traditional Age College Students (Unpublished Doctoral Dissertation, Catholic University of America). Dissertation Abstracts International, 145, 1268.

Hindal, H., Reid, N. and Whitehead, R. (2013). A Fresh look at High Ability. *International Journal of Instruction*, 6(1), 59-76.

Johnstone, A. H. (1991). Why is Science Difficult to Learn? Things are seldom what they seem. *Journal of Computer Assisted Learning*, 7, 75-83.

Johnstone, A. H. (1993). The Development of Chemistry Teaching - A Changing Response to Changing Demand, *Journal of Chemical Education*, 70(9), 701-705.

Johnstone, A. H. (1997). Chemistry Teaching, Science or Alchemy? *Journal of Chemistry Education*, 74(3), 262-268.

Johnstone, A.H. and Al-Naeme, F. (1991). Room for Scientific Thought?, *International Journal of Science Education*, 13(2), 187-192.

Johnstone, A.H. and El-Banna, H. (1986). Capacities, Demands and Processes: a Predictive Model for Science Education. *Education in Chemistry*, 23(3), 80-84.

Johnstone, A.H. and El-Banna, H. (1989). Understanding Learning Difficulties - A Predictive Research Model. *Studies in Higher Education*, 14(2), 159-68.

Jonassen, D. H. and Grabowski, B. L. (1993). Handbook of Individual Differences, Learning and Instruction. Hillsdale, NJ: Lawrence Erlbaum.

Korchin, S. J. (1986). Field-Dependence, Personality Theory and Clinical Research. In M. Bertini, L. Pizzamiglio and S Wapner (Eds.), Field-dependence in Psychological Theory, Research, and Appliction New York: Cambridge University Press.

Miller, G. D. (1956). The Magical Number Seven Plus or Minus Two: Some Limits on Our Capacity for Processing Information. *Psychological Reviews*, 63, 81-97.

Musser, T. (1998). Individual Differences, How Field-Dependence-Independence Affect Learners. Retrieved from: http: //www.personal.psu.edu/staff/t/x/txm4/paper1.htm1

Piaget, J. (1963). The Child's Conception of the World. Peterson, N. J.: Little Field, Adams.

Prasad, P.N. (2006). Performance of secondary students in India related to working memory with reference to some learning styles. MSc Thesis, Glasgow: University of Glasgow.

Reid, N. (2009). The Concept of Working Memory. Research in Science and Technological Education, 27(2), 131-138.

Reid, P.A. (2002). Problem solving by primary school children with particular reference to dyslexics. MSc Thesis, Glasgow: University of Glasgow.

Sawer, W. W. (1959). Mathematician's Delight. Harmondsworth: Penguin.

Scardamalia, M. (1977). Information Processing Capacity and the Problem of Horizontal Decalage: A Demonstration using Combinatorial Reasoning Tasks. Child Development, 48, 28-37.

Thurstone, L. L. (1944). A factorial study of perception. Chicago, IL: University of Chicago Press.

Tinajero C and Paramo M (1998). Field dependence-independence, cognitive style and academic achievement: A review of research and theory. *European Journal of Psychology of Education*, 13(2). 227-251.

Uz-Zaman, T. (1996). The Use of an Information Processing Model to Design and Evaluate Physics Undergraduate Laboratory. PhD Thesis, Glasgow: University of Glasgow.

Witkin , H. A. (1964). Origins of Cognitive Style. In C. Sheerer (Ed.). Cognition: Theory, Research and Promise. New York: Harper and Row.

Witkin, H. A., Dyk, R. B., Paterson, H. F., Goodenough, D. R, Karp, S.A. (1962). *Psychological Differentiation*. New York: Wiley.

Witkin, H. A. and Asch, S. E. (1948). Studies in Space Orientation (III).: Perception of the Upright in the Absence of Visual Field. *Journal of Experimental Psychology*, 38, 604-614.

Witkin, H. A. and Goodenough, D. R. (1981). Cognitive Styles Essence and Origins: Field Dependence and Field Independence Psychological Issues, New York: International University Press.

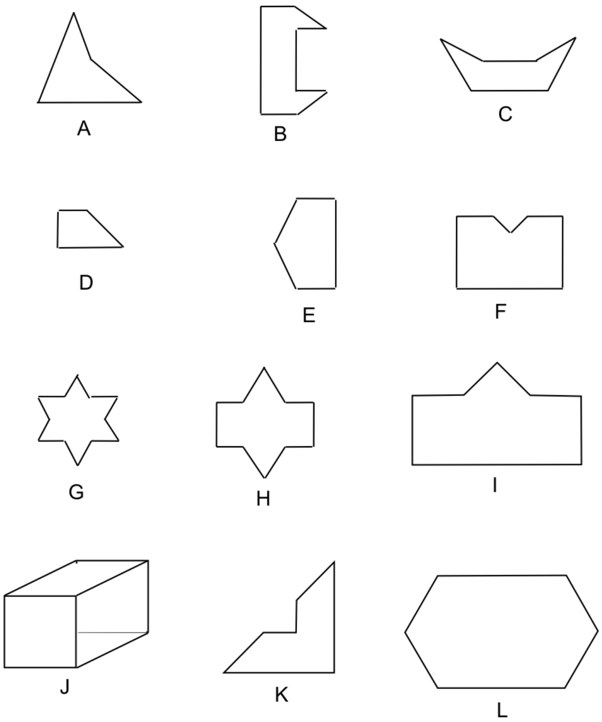
Witkin, H. A., Dyk, R. B. Faterson, H. F, Goodenough, D. R. and Karp, S. A. (1974). Psychological Differentiation: Studies of Development. New York: Lawrence Erlbaum Associates Inc.

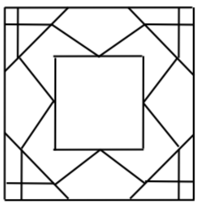
Witkin, H. A., Moore, C., Goodenough, D. and Cox, P. (1977). Field-dependent and Field-independent Cognitive Styles and their Educational Implications. *Review of Educational Research*, 47, 1-64.

Witkin, H. A., Oltman, P, Raskin, E., Karp, S. (1971). *A Manual for Embedded Figure Test*. Palo Alto, CA: Consulting Psychologists Press.

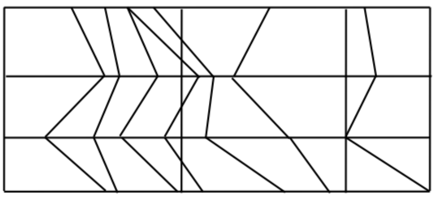
Appendix. First three sample items from Hidden Figures Test

The shapes you have to find

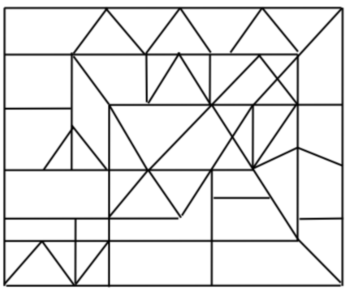




Find shape B



Find shape D



Find shape H