An Exploratory Analysis into the Relationships between Spatial Factors, Domain-Free General Capacities and General Fluid Intelligence

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Abstract

The inception of psychometric research concerning individual differences in cognition was grounded in explaining and enhancing performance in education (Spearman, 1904). This work established the construct of a single general intelligence often described as IQ. The aim of enhancing educational practices continues to underpin much of psychometric research, however Cattell (1943) postulated the potential for general intelligence to comprise of two separable entities; fluid intelligence (G*f*) and crystallised intelligence (G*c*).

Fluid intelligence is defined as "a facility in reasoning, particularly where adaptation to new situations is required" while crystallised intelligence is defined as "accessible stores of knowledge and the ability to acquire further knowledge via familiar learning strategies" (Wasserman & Tulsky, 2005, p.18). Within education the development of crystallised intelligence (G*c*) is arguably more visible as content knowledge is more easily assessed. The development of novel problem solving capacities is less discernible, however it can be supported by pedagogical strategies such as problem based learning (PBL).

This paper aims to afford an approach to the development of fluid intelligence (G*f*) through the identification of cognitive aptitudes aligning with this construct. It is envisioned that having a greater understanding of the cognitive faculties which support novel problem solving that pedagogical interventions such as the one described by Sorby (2009) could be scientifically developed and refined.

An exploratory analysis was conducted to identify associations between cognitive factors and fluid intelligence (G*f*). A cohort of initial technology teacher education (ITTE) students (N = 85) completed a battery of 17 psychometric tests selected as indicators for various cognitive constructs. Results illustrate an alignment between working memory capacity, spatial ability and inductive reasoning with fluid intelligence. Stemming from this, a discussion is presented discussing the potential for the translation of cognitive factors into STEM educational practices specifically focussing on technology education.

Keywords: Cognition, Problem solving, Fluid intelligence, Technology education.

Introduction

Broad educational aims vary between different cultures and levels of education. They also vary within these contexts at an individual discipline level however these differences are often more discrete. Considering technology education, there are many conceptions regarding the aims of the discipline. For example, Ritz (2009) describes essential goals of technological literacy programmes and the International Technology Education Association provides a list of goals for technology education which are similar but have minor variances (ITEA, 1990). A common aim found in these frameworks is one concerning the development of problem solving capacities. This is further exemplified in models of technological capability such as those offered by Black and Harrison (1985) and Gibson (2008). Operationalised through the integration of pedagogical strategies such as problem-based learning (PBL) (Williams, Iglesias, & Barak, 2008), there is a clear value in the development of these skills. A problem exists in the achievement of educational goals concerning these skills as while other aims of education, such as the acquisition of content knowledge, are visible and arguably more easily taught and assessed, the development of problem solving skills is more difficult to objectively identify. To assist in pertinent educational agendas, the body of research concerning cognitive development through applied psychometrics presents an auspicious approach which can be adopted.

The origin of psychometrics in education

The inception of psychometric research concerning individual differences in cognition was grounded in explaining and enhancing performance in education (Galton, 1879; Spearman, 1904). Through his early work, Spearman (1904) developed a conception of a single general intelligence which he termed '*g*', a construct now commonly known as IQ. Spearman's early work attempted to ascertain if "abilities commonly taken to be 'intellectual' had any correlation with each other or with sensory discrimination" (Spearman, 1930, p.322). The empirical evidence ultimately resulted in the formulation of his *two-factor theory*, a theory of intelligence containing the postulates of *g* and *s* (Spearman, 1927). In this theory, *g* was defined as "not any concrete thing but only a value or magnitude" (p.75), identified as representative of a general ability which is "common to all abilities that are interconnected by the tetrad equation" (p.76). Specific factors, denoted as '*s*', referred to factors of intelligence which emerged from specific tests or subtests but were not common to all tests in a battery. Spearman posited that the interaction between a person's general intelligence and a specific factor of intelligence was responsible for test performance. In essence, *g* described a level of domain general or independent ability while *s* referred to domain specific abilities.

Over time, Spearmans two-factor theory was developed to make explicit some of the specific factors contained within it (Holzinger & Harman, 1938; Holzinger & Swineford, 1939). At the same time, similar work was conducted by Thurstone (1938) who identified a series of *primary mental abilities* devoid of a *g* factor. These specific factors and primary mental abilities were the foundation for what are now referred to as second-order factors of intelligence and included constructs such as 'space', 'perceptual speed', 'number facility', 'verbal relations', 'word fluency', 'memory' and 'induction' (Thurstone, 1938). Within the Cattell-Horn-Carroll theory of intelligence (CHC theory) (Schneider & McGrew, 2012), these second order factors describe cognitive faculties comprising of groups of similar first-order factors which have emerged within the pertinent literature subsequent to the early work of Spearman and Thurstone.

The theory of separable fluid and crystallised intelligences

The theory of separate fluid and crystallised intelligences (Gf-Gc theory) was first theorised by Cattell (1941, 1943) as an advancement of Spearman's (1904) idea of a single general intelligence. Cattell (1943) conceived his theory of fluid and crystallised intelligences from observations of intelligence tests designed for children and their lack of applicability to adult populations. Synthesising the observations of the adult dissociation of cognitive speed from power and the diminished *g* saturation in adult intellectual performances with neurological evidence identifying localised brain legions as effecting children generally while a corresponding legion effecting adults more in terms of speeded tasks, abstract reasoning problems, and unfamiliar performances than in vocabulary, information and comprehension (e.g. Hebb, 1941, 1942), Cattell (1943) postulated the potential for general intelligence to comprise of the two separate entities. Fluid intelligence is defined as "a facility in reasoning, particularly where adaptation to new situations is required" while crystallised intelligence is defined as "accessible stores of knowledge and the ability to acquire further knowledge via familiar learning strategies" (Wasserman & Tulsky, 2005, p.18). Within education, this dichotomy is easily transferable with fluid intelligence being synonymous with novel problem solving and crystallised intelligence being synonymous with the acquisition and application of discipline specific content knowledge.

An agenda to synthesise factorial research within technology education

Considering the clearer visibility of crystallised intelligence within education and the aims concerning problem solving in technology education, it is currently more prevalent to construct a framework to support the development of fluid intelligence. Substantial research has investigated the association between fluid intelligence and education and with other cognitive factors. Lohman (1996) for example notes how fluid intelligence is a particularly good indicator of general education performance in many disciplines. As this correlation is well-established, pertinent correlations between cognitive factors may aid in its pragmatic synthesis within educational practices.

Specifically within Science, Technology, Engineering, and Mathematics (STEM) education disciplines, spatial ability has been shown to be a significant predictor of success (Lubinski, 2010; McGrew & Evans, 2004; Wai, Lubinski, & Benbow, 2009). Interestingly, spatial ability has also been shown to correlate significantly with fluid intelligence (Colom, Contreras, Botella, & Santacreu, 2001). Building on this, there has been a substantial degree of evidence showing a correlation between working memory and fluid intelligence (Kyllonen & Christal, 1990). The strength of this correlation led cognitive scientists to believe general intelligence and working memory were the same construct (Conway, Kane, & Engle, 2003), however they have since been dissociated as separate cognitive faculties (Ackerman, Beier, & Boyle, 2005). Considering the amalgam of this evidence, it may be possible that fluid intelligence within education can be developed by targeting aligning faculties such as spatial ability and working memory. Corresponding with this agenda, interventions have been developed for spatial ability (Sorby, 2009) and working memory (Harrison et al., 2013) and have been shown to have significant positive effects.

The current study

The ultimate goal of the previously described agenda is to enhance practice in technology education by virtue of the incorporation of cognitive training within traditional educational practices. Currently, operationalising this requires developing fluid intelligence and novel problem solving skills within students. However, fluid intelligence is a second-order factor and therefore is not directly measureable or targetable through intervention. Instead, the first-order factors associated with it must become the focus of interventions. While constructs such as spatial ability and working memory have been shown to correlate with fluid intelligence, research does not illustrate the full remit of first-order factors within these faculties that are important to this agenda. Furthermore, there are a number of domain-free general capacities which have not been examined to date. Therefore, the intent of this study is to examine the relationships between fluid intelligence and a broad array of domain-free general first order cognitive factors from a psychometric perspective to determine which cognitive faculties should become the focus of future work.

Method

Participants

A cohort of 3rd year undergraduate students (N=85) enrolled in an Initial Technology Teacher Education (ITTE) programme participated in this study. The cohort consisted of 80 males and five females. Their ages ranged from 19 to 31 with a mean of 21.19 and a standard deviation of 2.41. Participation in this study was voluntary.

Tests

Participants were invited to take a total of 17 psychometric tests with each one representing a unique first-order factor of human intelligence. These tests were predominantly adopted from the Educational Testing Services' (ETS) Kit of Factor Referenced Cognitive Tests (Ekstrom, French, Harman, & Derman, 1976), however additional tests were utilised to reflect advances in psychometric research. The second order factors included in this study were visual processing (spatial ability), long-term memory, short-term memory, general reasoning, and processing speed. Table 1 provides a detailed description of each test utilised within this study.

Participants engaged with the tests in five groups of approximately 17 people. The tests were administered over a course of four test sessions with one week passing between each session. No session lasted longer than 60 minutes in duration and tests were administered in a different order to each group to remove the potential for an order bias within the data.

Table 1. Descriptions of psychometric tests utilised in the study.

Test *(second-order factor: first-order factor)*
Ravens Advanced Progressive Matrices Test *(fluid intelligence)*
For each problem, participants were presented with a 3 x 3 matrix containing eight abstract figures and one empty space. Participants had to select one of nine multiple choice answers which would fit the pattern of the matrix. The 32 items from part two of the test were used. A total time of 40 minutes was afforded for the test.
ETS Paper Folding Test *(visual processing: visualisation)*
For each problem, participants were presented with a series of illustrations showing a piece of paper being folded up to three times and having a hole punched in it. Participants had to select one of five multiple choice answers which would identify the piece of paper after it had subsequently been unfolded. The 20 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.
Mental Rotations Test *(visual processing: spatial relations)*
For each problem, participants were presented with an abstract stimulus constructed of an arrangement of cubes. Participants had to select two of four multiple choice answers which identified the original stimulus but in a different orientation with the remaining two being different (mirror images). The 24 items across parts one and two

Test *(second-order factor: first-order factor)*
of the test were used. A total time of three minutes was afforded for each part of the test.
ETS Card Rotations Test *(visual processing: speeded rotations)*
For each problem, participants were presented with an abstract 2-dimensional stimulus. Participants had to identify if eight successive stimuli were the same or different (mirror images) to the original stimulus. The 160 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.
Perspective Taking Spatial Orientation Test *(visual processing: spatial orientation)*
For each problem, participants were presented with an array of images represented real life objects (e.g. a tree, car and house), and instructions telling them which object they were to imaging being their location, which object they had to image they were facing, and which object they had to mentally point to. Participants had to identify which direction they were pointing in on a chart immediately below the array of objects. The 12 items from the test were used. A total time of five minutes was afforded for the test.
ETS Gestalt Completion Test *(visual processing: closure speed)*
For each problem, participants were presented with an incompletely drawn image of a real life object (e.g. a flag or hammer). Participants had to identify what the object in each image was. The 20 items across parts one and two of the test were used. A total time of two minutes was afforded for each part of the test.
ETS Hidden Patterns Test *(visual processing: flexibility of closure)*
For each problem, participants were presented with a 2-dimensional array of lines. Participants had to identify if a common line diagram was or was not present within the array. The 400 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.
ETS Shape Memory Test *(visual processing: visual memory)*
For each problem, participants were presented with an array of abstract visual stimuli which they had to memorise. Participants had to identify if a selection of abstract stimuli were or were not present within the memorised array. The 32 items across parts one and two of the test were used. A total time of eight minutes (four memorising, four answering) was afforded for each part of the test.
ETS Maze Tracing Speed Test *(visual processing: spatial scanning)*
For each problem, participants were presented with a 2-dimensional maze consisting of 24 adjoining sections. Participants had to identify the correct path through the maze. The 48 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.
Transformation Test *(visual processing: imagery quality)*
For each problem, participants were presented with verbal information describing instructions of how to mentally manipulate simple figures (e.g. letters, numbers and shapes). Participants had to identify the final figure after all instructions and illustrate this through a sketch. The 12 items across parts one and two of the test were used. A total time of 12 minutes was afforded for the test.
ETS Picture Number Test *(long-term memory: associative memory)*
For each problem, participants were presented with an array of images of real life objects and a number associated with each of them which they had to memorise. Participants had to identify the number associated with each object after the numbers were removed and the order of the images changed. The 32 items across parts one and two of the test were used. A total time of eight minutes (four memorising, four

Test *(second-order factor: first-order factor)*
answering) was afforded for each part of the test.
ETS Toothpicks Test *(long-term memory: figural flexibility)*
For each problem, participants were presented with an image showing a pattern constructed of straight lines representing toothpicks and instructions describing a final pattern and how many lines must be removed. Participants had to identify a final pattern which conformed to the given rules in up to five unique ways. The 50 items across parts one and two of the test were used. A total time of six minutes was afforded for each part of the test.
ETS Auditory Number Span Test *(short-term memory: memory span)*
For each problem, participants were presented verbally with sequences of between four and 12 numbers with one second between each number in the sequence. Participants had to identify the exact sequences once all numbers in them had been announced. The 24 items in the test were used. A total time of eight minutes was afforded for the test.
ETS Figure Classification Test *(general reasoning: inductive reasoning)*
For each problem, participants were presented with either two or three groups of abstract visual figures where each group had a specific rule or condition regarding the figures within it which differentiated it from the other group(s). Participants had to identify which of the groups a series of additional figures belonged to. The 224 items across parts one and two of the test were used. A total time of eight minutes was afforded for each part of the test.
ETS Nonsense Syllogisms Test *(general reasoning: deductive reasoning)*
For each problem, participants were presented with a written statement, constructed with nonsensical content, which was exemplary of either good or poor reasoning. Participants had to identify if the statements illustrated good or poor reasoning. The 30 items across parts one and two of the test were used. A total time of four minutes was afforded for each part of the test.
ETS Finding A's Test *(processing speed: perceptual speed – letters)*
For each problem, participants were presented columns of 41 words, five of which contained the letter 'A'. Participants had to identify which of the words contained the letter 'A'. The 200 items across parts one and two of the test were used. A total time of three minutes was afforded for each part of the test.
ETS Identical Pictures Test *(processing speed: perceptual Speed – images)*
For each problem, participants were presented with an abstract 2-dimensional stimulus. Participants had to identify the identical stimulus within a set of five stimuli to its immediate right. The 96 items across parts one and two of the test were used. A total time of 1.5 minutes was afforded for each part of the test.

Note. All ETS tests came from the Kit of Factor References Cognitive Tests (Ekstrom et al., 1976), additional tests include the Ravens Advanced Progressive Matrices Test (Raven, Raven, & Court, 1998), the Mental Rotations Test (Vandenberg & Kuse, 1978), the Perspective Taking Spatial Orientation Test (Hegarty & Waller, 2004), and the Transformation Test (Finke, Pinker, & Farah, 1989).

Data preparation and screening

Due to participants missing scheduled test sessions for various reasons, 12.60% of the data (182 test scores) was missing from the complete dataset. In addition, eight participants did not finish the Perspective Taking Spatial Orientation Test within the allocated time limit and due to the approach taken in scoring this test this imposed a significant impact on the normality of the results. These test scores were therefore omitted from the dataset. Combined, these missing scores corresponded to a total of 13.15% of missing data leaving a total of 1255 test scores in the dataset. The missing data was computed with a full-information maximum likelihood (FIML) estimate within the AMOS software (v.21, IBM SPSS Statistics). This approach was selected to avoid the randomness introduce by imputation techniques (Dong & Peng, 2013).

The dataset which included only the 1255 original tests was used to determine the descriptive statistics (Table 2) and correlation matrix (Table 3) and the dataset with missing values computed was used for the exploratory factor analysis (EFA). As EFA's assume multivariate normal distributions and are sensitive to extreme outliers, the data was screened for both univariate and multivariate outliers prior to the conduction of these tests (Kline, 2016). Univariate outliers were identified as results which exceeded three standard deviations from the mean. Seven test results (0.48% of the dataset) were identified as univariate outliers under this criterion and were transformed to the value equal to three standard deviations from the mean (Kline, 2016). Data was then screened for multivariate outliers using both the Mahalanobis D and Cook's D statistics. The criterion for identifying outliers with the Mahalanobis D statistic was $p < 0.001$ (Kline, 2016) and for the Cook's D statistic it was any instance greater than 1 (Cook, 1977). No data was identified as a multivariate outlier.

Results

Descriptive statistics of the raw scores from each of the tests are illustrated in Table 2. Skewness and kurtosis values for all tests are within acceptable limits of between ±2 (Gravetter & Wallnau, 2014; Trochim & Donnelly, 2006). Despite some of the α values being below the recommended value of .7 (Nunnally, 1978), as all of the tests utilised in the study are well-established and have been previously validated this was deemed acceptable.

To determine relationships between each of the cognitive factors being examined within this study, correlations were computed between each test and an EFA was conducted. The correlation matrix is presented in Table 3.

Table 2. Descriptive statistics

Task	N	M	SD	Range	Skewness	Kurtosis	α
1. Paper Folding	72	12.11	3.13	16.00	-.26	.13	.73
2. Mental Rotations	79	13.33	4.43	18.00	.13	-.85	.81
3. Card Rotations	65	114.29	24.33	95.00	-.04	-.66	.97
4. Perspective Taking	71	152.97	14.83	67.17	-1.04	.68	.63
5. Gestalt Completion	72	14.63	2.71	11.00	-.93	.45	.61
6. Hidden Patterns	72	217.65	55.75	286.00	-.49	.22	.98
7. Shape Memory	68	24.99	3.19	14.00	-.52	-.07	.56
8. Maze Tracing	82	30.35	6.58	33.00	.25	.42	.93
9. Transformation	82	20.56	2.94	13.00	-1.21	1.38	.63
10. Picture Number	75	25.13	9.35	34.00	-.38	-.91	.91
11. Toothpicks	74	10.07	5.27	21.00	.28	-.74	.63
12. Auditory Number Span	82	10.01	2.75	14.00	.25	.02	.71
13. Figure Classifications	75	130.49	32.88	145.00	-.18	-.58	.98
14. Nonsense Syllogisms	73	14.53	4.16	20.00	.06	-.16	.80
15. Finding A's	63	50.94	12.67	59.00	.63	.39	.92
16. Identical Pictures	77	83.05	10.50	43.00	-.91	.31	.93
17. Ravens Advanced Matrices	73	23.43	4.97	25.00	-.61	.25	.87

Table 3. Correlation matrix

Task	Statistic	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Paper Folding	Pearson's r	–																
	N																	
2. Mental Rotations	Pearson's r	.439**	–															
	N	70																
3. Card Rotations	Pearson's r	.334*	.531**	–														
	N	58	62															
4. Perspective Taking	Pearson's r	.303*	.322**	.285*	–													
	N	62	71	55														
5. Gestalt Completion	Pearson's r	.282*	.325**	.262*	.280*	–												
	N	72	70	58	62													
6. Hidden Patterns	Pearson's r	.255*	.026	.032	.143	.239*	–											
	N	72	70	58	62	72												
7. Shape Memory	Pearson's r	.453**	.275*	.031	.360**	.289*	.241	–										
	N	62	64	57	56	62	62											
8. Maze Tracing	Pearson's r	.418**	.175	.359**	.068	.144	.209	.168	–									
	N	69	76	62	68	69	69	68										
9. Transformation	Pearson's r	.401**	.382**	.177	.145	.318**	.247*	.204	.272*	–								
	N	69	76	62	68	69	69	68	82									
10. Picture Number	Pearson's r	.145	.078	.160	.134	.167	.140	.426**	.201	.152	–							
	N	65	71	59	63	65	65	62	73	73								
11. Toothpicks	Pearson's r	.350**	.400**	.313*	.141	.122	.222	.072	.332**	.347**	.085	–						
	N	63	71	59	63	63	63	58	72	72	67							
12. Auditory Number Span	Pearson's r	.182	.287*	.224	.157	.168	.142	.186	.035	.037	.200	.119	–					
	N	69	76	62	68	69	69	68	82	82	73	72						
13. Figure Classifications	Pearson's r	.274*	.241*	.175	-.086	.139	.437**	.322*	.362**	.386**	.279*	.351**	-.046	–				
	N	65	71	59	63	65	65	62	73	73	75	67	73					
14. Nonsense Syllogisms	Pearson's r	-.034	.162	.114	.041	.102	-.030	-.017	.181	.182	.162	.065	.213	.027	–			
	N	63	70	58	62	63	63	57	71	71	66	73	71	66				
15. Finding A's	Pearson's r	.024	-.029	.100	.007	.298*	.090	.083	.066	.064	.115	-.119	-.014	.254	-.100	–		
	N	57	60	58	52	57	57	59	61	61	57	58	61	57	57			
16. Identical Pictures	Pearson's r	.300*	.277*	.466**	.009	.421**	.140	.148	.489**	.370**	.294*	.342**	-.102	.326**	-.122	.181	–	
	N	70	74	62	66	70	70	65	74	74	69	68	74	69	67	61		
17. Ravens Advanced Matrices	Pearson's r	.533**	.218	.211	.181	.341**	.309*	.534**	.247*	.272*	.428**	.174	.122	.453**	.039	.126	.278*	–
	N	66	71	58	63	66	66	63	71	71	67	66	71	67	65	59	68	

Note: *. correlation is significant at the 0.05 level (two-tailed)
Note: **. correlation is significant at the 0.01 level (two-tailed)

EFA was selected over a principle component analysis (PCA) as the intent of this analysis was to determine underlying relationships between the variables in the dataset (Byrne, 2005). Specifically, the maximum likelihood method of extraction was selected as in the data screening stage assumptions of normality were not violated (Fabrigar, Wegener, Maccallum, & Strahan, 1999). An oblique rotation was selected as it was hypothesised that the factors would correlate (Osborne, 2015) with both promax and direct oblimin methods being examined. As no significant difference was observable between the two methods the promax solution is described below.

For the EFA, 14 of the 17 variables correlated at least .3 with at least one other variable. The Kaiser-Meyer-Olkin measure of sampling adequacy was .71, above the recommended value of .6, and Bartlett's test of sphericity was significant (χ^2 (136) = 353.48, p < .000). These criteria suggest a reasonable level of factorability within the data. A scree plot (Figure 1) was examined to determine the number of factors to extract. The scree plot suggested a three factor model. The initial eigenvalues showed that the first factor explained 25.137% of the variance, the second factor 9.527% of the variance, and a third factor 8.953% of the variance. Four, five, and six factor solutions were also examined but the three factor solution was preferred because of its theoretical support.

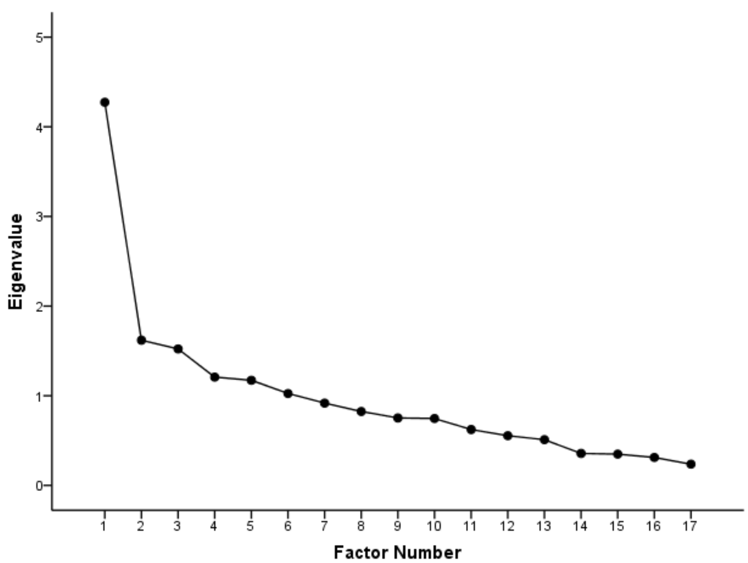

Figure 1. Scree plot and extracted eigenvalues suggesting a three-factor solution

The results from the EFA are presented in Table 4. An examination of the three factors reveals interesting underlying relationships which aid in their interpretation. The primary tests loading on the first factor are predominantly speeded tests (e.g. Identical Pictures, Mental Rotations, Card Rotations, and Maze Tracing). Interestingly, the Toothpicks test also loaded on this factor despite having little in common with the primary loading tests. The Transformation and Gestalt Completion tests require the construction of a mental image and are arguably perceptual tests more than speeded tests. However, the statistically significant correlation (*r* = .347, *p* < .01) between the Toothpicks Test and Transformation Test illustrates that mental imagery has a role in figural flexibility which is theoretically sound. Synthesising the correlations with the factor loadings, this first factors appears to represent a factor associated with cognitive speed.

The second factor is of particular interest to this study. The Ravens Advanced Progressive Matrices Test was of significant interest due to its representation of fluid intelligence and is the highest loading variable on this factor. Also loading on this factor are the Shape Memory and Picture Number tests, the Figure Classifications Test and the Paper Folding Test. Examining all of these, and the tests not loading on this factor, suggests that this factor is associated with cognitive power. Perhaps more interestingly, it suggests that memory span, inductive reasoning, and visualisation are the primary cognitive factors associated with novel problem solving. The Hidden Patterns Test also loaded on this factor and it was theorised that this test would load on the first factor due to the speeded nature of the test. Considering the nature of the problems within the test, it may load on this factor as it requires more than observation of the stimuli and the act of decoding the information within the distracting array of lines may require a higher degree of cognitive power than other speeded tests.

The third factor has loadings from the Mental Rotations Test, the Paper Folding Test and the Perspective Taking Spatial Orientation Test. Despite each being associated with a different spatial factor, they all involve dissociable elements of mental rotation. Combined with the moderate negative loading from the Identical Pictures Test this factor appears to represent cognitive action more than just observation. It appears to be a factor describing spatial skills independent of perceptual and memory factors within the faculty. This is interesting as the evidence shows it as dissociable from the other two factors, aligning with the prominent understanding that spatial ability is a unique cognitive domain. The additional loading from the Auditory Number Span Test illustrates that working memory span also has a bearing on spatial skills.

Finally, an observation of the correlations between factors shows a moderate correlation between factors one and two (r = .496), with only small correlations between factors one and three (r = .112) and factors two and three (r = .239) which suggests that while separable, cognitive speed and power do share a moderate degree of variance in cognitive performance.

Table 4. Factor loadings for the maximum-likelihood EFA factor solution

Measure	**Factor 1**	**Factor 2**	**Factor 3**
Identical Pictures	**.925**	.044	**-.453**
Mental Rotations	**.593**	-.162	**.567**
Card Rotations	**.584**	-.206	.243
Toothpicks	**.422**	-.016	.212
Maze Tracing	**.411**	.223	-.077
Transformation	**.367**	.186	.133
Gestalt Completion	**.366**	.210	.047
Ravens Matrices	-.020	**.723**	.087
Shape Memory	-.081	**.641**	.117
Hidden Patterns	-.089	**.504**	-.015
Figure Classifications	.108	**.486**	-.043
Picture Number	.072	**.473**	-.089
Paper Folding	.255	**.379**	**.330**
Finding As	.016	.210	-.166
Auditory Number Span	.024	.055	**.393**
Perspective Taking	.117	.047	**.332**
Nonsense Syllogisms	-.011	-.027	.289

Discussion

The results of this study provide a substantial contribution in terms of identifying suitably targetable cognitive faculties to enhance problem solving abilities in technology students. Cognisance should be taken however within this approach to the dichotomy of the problem space and the task environment (Newell & Simon, 1972; Simon & Newell, 1971), constructs which are analogous to the Assessment of Performance Unit (APU) model describing the interaction between mind and hand (Kelly, Kimbell, Patterson, Saxton, & Stables, 1987). This approach aims to directly target the capacities of the mind, which can affect people's external actions but may not directly affect their tacit capacity to physically manipulate the environment or objects within it.

The findings of this study, both the correlations and EFA results, suggest three predominant cognitive faculties which should be targeted by future interventions. These include working memory span, inductive reasoning and spatial ability. It is posited that the strength and significance in the association between working memory span and fluid abilities stems from the increased capacity to hold relative information in the working memory while problem solving. In terms of the association with spatial ability, it is posited that this supports the ability to generate and manipulate the information within the working memory. Finally, inductive reasoning is posited to provide people with the capacity to make inferences from pertinent information. Ultimately, the amalgam of these cognitive skills is postulated as foundational in supporting a person in problem solving from a cognitive perspective.

Future work on this agenda should involve a more extensive analysis of the data and a rigorous investigation into the causation underpinning the associations between spatial ability, working memory and inductive reasoning with fluid intelligence. Ultimately, this information could then be used for the further develop existing interventions or to create a bespoke intervention suitable to technology education.

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