Executive Functions Predict Conceptual Learning of Science

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Abstract

We examined the relationship between executive functions and both factual and conceptual learning of science, specifically chemistry, in early adolescence. Sixty-three pupils in their second year of secondary school (aged 12-13 years) participated. Pupils completed tasks of working memory (Spatial Working Memory), inhibition (Stop-Signal), attention set-shifting (ID/ED), and planning (Stockings of Cambridge), from the CANTAB. They also participated in a chemistry teaching session, practical and assessment on the topic of acids and alkalis designed specifically for the current study. Executive function data was related to a) the chemistry assessment which included aspects of factual and conceptual learning and b) a recent school science exam. Correlational analyses between executive functions and both the chemistry assessment and science grades, revealed that science achievements were significantly correlated with working memory. Linear regression analysis revealed that visuo-spatial working memory ability was predictive of chemistry performance. Interestingly, this relationship was observed solely in relation to the conceptual learning condition of the assessment highlighting the role of executive functions in understanding and applying knowledge about what is learned within science teaching.

Accumulating evidence shows that cognitive functions are related to science learning in children and adolescents. Research has, in particular, highlighted the role of higher order cognitive functions, known as executive functions, in science achievements and learning. Most of these studies have focused on working memory involving the ability to hold and manipulate information in mind. While various models of working memory have been proposed (e.g. Baddeley, 1986; Cowan, 1995; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Oberauer, 2009; Shah & Miyake, 1996) the weight of evidence supports Baddeley's theoretical working memory component model (Baddeley & Hitch, 1974; Baddeley, 1986, 2006). Several of the studies conducted on science learning have applied this model within their research design (e.g. Jarvis and Gathercole, 2003). This model includes verbal (phonological loop) and spatial (visuo-spatial sketchpad) components of working memory involved in the storage of information and a 'central executive' that regulates the overall working memory system and is responsible for attention control and co-ordination of the phonological loop and visuo-spatial sketchpad.

From a developmental perspective, it is well established that working memory develops across childhood and into adolescence (De Luca et al., 2003; Luciana and Nelson, 1998; Rhodes, Murphy & Hancock, 2011). Gathercole and colleagues (Gathercole, Pickering, Ambridge & Wearing, 2004) reported increases in working memory performance between ages 4 and 15. Similarly, Luciana, Conklin, Hooper and Yarger (2005) found that performance on complex visuo-spatial working memory tasks, such as self-ordered search tasks, continues until 16 years of age. Huizinga, Dolan and van der Molen (2006) examined executive functions in participants within 4 age groups (7, 11, 15 and 21) and reported that working memory development continued into young adulthood. The continued development of working memory suggests implications for learning of science subjects into the secondary school years.

There is an established link between working memory and a range of areas of academic learning such as reading (Daneman and Carpenter, 1980), language (Daneman and Merickle, 1996) and mathematics (Bull and Scerif, 2001). Researchers that have examined working memory and science learning similarly suggest that working memory may be important for learning science. Danili and Reid (2004) examined the relationship between chemistry learning and performance on a backward digit span working memory task – a verbal task which taps the phonological loop and central executive. This study reported a significant correlation between verbal working memory and performance on a chemistry test in Greek pupils aged 13-15 years. Tsaparlis (2005) reported similar correlational findings using a backward digit span task and a chemistry assessment with a large sample of first year undergraduate chemistry students. Gathercole, Pickering, Knight & Stegmann (2004) examined the relationship between verbal short-term and working memory and science achievement in a UK sample of pupils aged 14-15 years. Correlations were observed between science achievement and short-term (Digit Recall) and working memory (Backwards Digit Recall), but the relationship was stronger for the working memory task.

Two studies have examined verbal and visuo-spatial short-term memory and working memory in relation to science learning. Jarvis and Gathercole (2003) reported that visuo-spatial central executive scores were significantly correlated with science levels in a UK sample of 14 year old pupils. Verbal and visuo-spatial short-term memory components in contrast were not related to science learning. The findings emphasise the role of working memory in science learning and also suggest a critical role for visuo-spatial over verbal working memory. St-Clair Thompson and Gathercole (2006) assessed a UK sample of 11-12 year old pupils and reported that the relationship between working memory and science achievement was domain specific; visuo-spatial but not verbal working memory was related to performance on the science test.

Effective understanding of science involves a wider range of cognitive skills than just working memory processing. Science learning requires the ability to plan solutions to problems, to engage in hypothesis making, to examine and evaluate data, to think flexibly between different options, and to speculate on the influence of experimental manipulations. Such thinking is likely to rely on various strategic thinking/executive functions. Executive function is a broad term used to describe essential organisational processes that go beyond working memory to include a range of other strategic processes. The most commonly held view is that a common mechanism underlies all executive function processes but that executive functions are clearly separable (Miyake et al., 2000). It has been proposed that key aspects of executive function include: anticipation and deployment of attention, impulse control and self-regulation, initiation of activity, working memory, mental flexibility and utilisation of feedback, planning ability and organisation, and selection of efficient problem solving strategies (Anderson, 2008). While theoretical explanations of executive functions place different emphasis on these processes, most implicate inhibition, working memory and attention set-shifting as core processes (Miyake et al., 2000) with planning also receiving recent emphasis in the literature (Diamond, 2013).

There is consistent evidence that profound changes in executive functions continue across the period of adolescence (Anderson et al., 2001; DeLuca et al., 2003, Levin et al., 1991; Luciana and Nelson, 1998; Rhodes, Murphy, Hancock, 2011) reflecting protracted development of the pre-frontal cortex (O'Hare & Sowell, 2008). A number of studies have reported that inhibitory control emerges and matures early in childhood. For example, Pritchard and Neumann (2009) reported adult levels of performance on an inhibitory task in 5-year- old children. Other studies, however, have found that inhibition develops across childhood and into adolescence, up to age 17 in one study (Leon-Carrion et al., 2004). Inconsistent findings are highly likely to reflect task demands and the development of different aspects of inhibitory control (Harnishfeger, 1995). The evidence is more consistent for continued development of attention flexibility into adolescence. Anderson et al. (2001) reported that attentional flexibility had the most rapid growth spurts between 7-9 and 15 years of age and Davidson et al. (2006) showed that cognitive flexibility was still not at adult levels at 13 years of age. Planning ability also appears to mature later with reports of maturation around 12 years of age (Davidson et al., 2006). Thus, there is consistent evidence that most aspects of executive function have not matured by the time children start secondary school education.

Accumulating evidence suggests a role for broader aspects of executive function beyond working memory in science learning. St-Clair Thompson and Gathercole (2006) examined the relationship between inhibition, attention shifting (in addition to working memory) with mathematics, English and science learning in 11-12 year old children. Both inhibition and working memory were related to science learning. Further evidence was reported by Latzman, Elkovitch, Young, & Clark (2010); they found a relationship between science ability and inhibitory control and attention flexibility in a sample of 11-16 year old boys. A recent study (Rhodes et al., 2014) examined the relationship between executive functions and science learning specifically in relation to learning biology. Rhodes et al. (2014) reported a relationship between planning and factual learning of biology. Both spatial working memory and planning were associated with conceptual learning (understanding and applying) of biological knowledge. These findings suggest the role of executive functions in science learning may be broader than working memory and that executive functions may be particularly important when pupils have to understand and apply their knowledge to problems. It is yet unknown whether these findings concerning the relationship between executive functions and type of learning is science discipline specific. The current study aimed to extend these by examining these relationships in relation to pupils' learning of chemistry.

The current study aimed to build on the limited research that has examined science learning and executive functions. Here we assess a range of aspects of executive functions, including inhibition, working memory and attention set-shifting highlighted in the literature as core executive processes. We also assessed planning given its centrality to core aspects of science learning such as the experimental process. With previous reports that working memory and other aspects of executive function may not be at adult levels during the pre-adolescent stage, the current study examined these relationships in 12-13 year old children who had been attending secondary level education for approximately 18 months. The current study examined science learning at the point of the introduction of a new curriculum in Scotland, the Curriculum for Excellence (Scottish Executive, 2004). The focus within this curriculum is on active learning and peer collaboration. The curriculum moves from a focus on investigative aspects of science within the primary school years (up to age 12) to content and skills, including both acquiring knowledge through learning facts, planning investigations, and examination and evaluation of data in the early secondary school years. Most previous research in this area has provided generic science assessment grades and has not differentiated between fact based retrieval and the application of knowledge/conceptual learning and understanding of science. The current study set out to investigate the role of executive functions in both fact and conceptual learning of science.

Here, we assessed the relationship between executive functions and performance on both a generic science exam and in relation to a study specific chemistry teaching session and assessment. Based on existing literature, it was predicted that science grades on both the chemistry assessment and the science exam would be related to working memory and that inhibition, attention set-shifting and planning would also predict science learning. In particular, we predicted that executive functions would relate to performance on the conceptual part of the chemistry assessment where pupils had to reflect and apply the knowledge they had acquired. Given previous findings of a role for planning in factual and conceptual learning of biology (Rhodes et al., 2014), we predicted that planning may relate to both aspects of learning chemistry, although due to a lack of relevant literature it is possible that there may be discipline specific differences in findings.

Method

Participants

Sixty-three pupils (aged 12-13 years) were recruited to the study from four secondary schools within the North Lanarkshire Council area of Scotland. Schools were all located in urban areas spread across the authority. Each of the schools followed the National Curriculum independently. The schools were chosen as they are representative of having an average level of deprivation (average deprivation score indicated by free school meal data is 16% versus Scotland average of 19.8%). The study received ethical approval from the Departmental Ethics Committee and consent was obtained from parents of all participating children. The sample comprised both boys (N = 25) and girls (N = 38). No pupils refused to participate. Teachers of all consenting pupils completed the Strengths and Difficulties Questionnaire (SDQ, Goodman, 2001) to screen for any potential psychiatric/behavioural disorder known to be associated with impaired executive functions (e.g. ADHD). Fifty-six pupils were rated within the normal range on the SDQ and their data were included in the analyses. Pupils had a mean age of 12.9 (S.D.0.18). All pupils completed the British Picture Vocabulary Scale II (Dunn, Dunn, Whetton, & Burley, 1997) to provide a measure of vocabulary ability that is independent of executive function skills. All pupils scored within the normal range on this test.

Materials and Procedure

Cognitive Tasks

All participants completed four tasks from the Cambridge Neuropsychological Test Automated Battery (CANTAB) (Morris, Evendon, Sahakian, & Robbins, 1987): the Spatial Working Memory (working memory), Stockings of Cambridge (planning), Stop-Signal (inhibition) and ID/ED (attention set-shifting). These tasks were chosen because they have been extensively validated in both child and adult populations (Curtis, Lindeke, Georgieff & Nelson, 2002; Luciana & Nelson, 1998; Rhodes, Coghill, Matthews, 2004, 2005, 2006; Robbins, James, Owen, Sahakian, McInnes, & Rabbitt, 1994) and typical developmental trajectories of performance have been reported (Curtis et al., 2002; Luciana & Nelson, 1998; Robbins et al., 1994). All of the tasks used in the current study rely on non-verbal executive function skills. Tasks are performed on a touch-screen computer and are highly suitable for use with children.

Working Memory:

The Spatial Working Memory (SWM) task places heavy demands on central executive functioning. It is a self-ordered searching task (Petrides & Milner, 1982) that assesses the participant's ability to retain visuo-spatial information and to store and simultaneously manipulate information in working memory while working towards a goal. Participants are required to 'search through' a spatial array of coloured boxes presented on the screen to collect 'blue tokens' hidden inside the boxes. Returning to a box where a token has already been found constitutes a 'Between Search Error' (BSE). The key measure, total Between Search Errors, is generated through the addition of the number of errors across the 4, 6, and 8 box stages of the task. Participants must keep searching through all the boxes until they find the blue token at which point they proceed to find the next hidden blue token. Ultimately participants will find a blue token behind each of the boxes. Experimental trials commence with a four box search and the highest difficultly level involves eight box trials. Participants can use a (self-initiated) strategy to aid performance, for example always starting at top left of the array of boxes moving across to bottom right.

Inhibition:

The Stop-Signal task provides an assessment of response inhibition. This task measures the ability of an individual to inhibit a prepared motor response, requiring participants to respond or withhold responding dependent on receiving an auditory signal. This test consists of two parts. In the first one, the training part, the participants are told to press the left hand button when they see a left-pointing arrow and the right hand button when they see a right pointing arrow. In the second part, participants continue pressing the buttons on the press pad when they see the arrows but, if they hear an auditory signal (a beep) which occurs on 25% of trials, they withhold their response to press the button. The stop-signal paradigm allows a sensitive estimate of inhibitory control—the stop-signal reaction time (SSRT)—reflecting the time it takes to suppress a response. The timing of the auditory stop signal varies throughout the test, depending on the participant's past performance, so that stopping occurs around 50% of the time for each participant. This enables the provision of an estimate of the participant's ability to inhibit a pre-potent response.

Attention set-shifting:

The executive ID/ED task assesses attention set-shifting, involving the ability to shift flexibly from focusing attention on one aspect of stimulus to another. Specifically, the task measures a participant's ability to focus attention on specific attributes of compound stimuli (intra-dimensional stages) and to shift attention when required to a previously irrelevant stimulus dimension (extra-dimensional stages). At each stage of the task two different stimuli are presented (e.g. solid shape) and participants are instructed to choose the stimulus they think is the correct one after which they receive feedback. Once the participant correctly chooses the same stimuli over 6 trials the task moves to the next stage. The intra-dimensional stages involve shifting from one solid shape to another whereas the executive extra-dimensional stages require shifting from one type of stimulus to another (solid shape to a line). The key measure on this task is the Stage Reached Score (up to a maximum of stage nine). Reaching the final stages indicates the ability to engage in executive set-shifting (reaching stage eight) and reversal (reaching stage nine).

Planning:

The Stockings of Cambridge task measures planning ability and makes substantial demands on executive function. This task was derived from the 'Tower of Hanoi' task (Shallice, 1982). This is a complex task that, while principally a measure of planning, also relies on the three core aspects of executive function, namely inhibition, working memory and attention shifting. Participants must move balls to match a ‘goal’ arrangement. Problems can be solved in a certain ‘Minimum Number of Moves’ (two, three, four or five moves). Initial and Subsequent ‘Thinking’ Times during trials are recorded to provide estimates of cognitive speed during the preparatory and execution phases of task performance. For each trial, a yoked control condition is also executed to enable estimates of ‘movement times’ in order to provide an estimate of cognitive deliberation/planning times in the test conditions. The key measure on this task is the number of Problems Solved in the Minimum Number of Moves.

Cognitive Testing:

The order of cognitive tasks was counterbalanced across participants. Testing was conducted in a quiet room in the participant’s school.

Science Grades: The grade achieved (% accuracy) on the most recent science assessment completed at the end of the first term of the second year of high school and marked by the school science teacher, 6-8 weeks prior to the executive function testing, was correlated with performance on the executive function tasks. This routine end-of-term test was conducted as part of the normal science curriculum in Scottish secondary schools. The test comprised an assessment of physics, chemistry, and biology learning from which one overall science test grade was computed for each participant. The assessments in all four schools were in the form of a written exam and assessed recall of facts and problem solving. These were school specific exams and their content will have varied between schools. From this, teachers derived an overall numerical grade for each pupil.

Chemistry Practical:

Pupils attended a 45 minute teaching session facilitated by a PowerPoint presentation on the basics of acids and alkalis. Areas covered included: the definition of an acid in terms of hydrogen ion concentration and the definition of an alkali in terms of hydroxide ion concentration; the definition of strong and weak in terms of the degree of dissociation, and examples for each; what happens when an acid and alkali react together; the definition of pH and some relevant examples of acidic, alkaline and neutral solutions; and, the reaction between metals and acids. The presentation was followed by a detailed description of the practical task to be completed and accompanied by a PowerPoint slide.

The class was divided into small groups for the practical which was supervised by three research assistants (facilitators). The pupils were supplied with a package containing all the materials required to determine the pH of common household items. pH testing was completed by the pupils dipping pH paper into pre-prepared solutions and comparing the pH paper colour change to a standard pH colour chart provided. From the results, pupils had to decide on the pH of the solution (to the nearest whole pH unit) and decide whether the household item being tested was an acid or an alkali.

While pupils were analysing samples, the facilitators circulated through the groups, encouraging discussion on the observations that were being made and questioning whether they were obtaining results expected. In the second part of the experimental section, pupils were given iron fillings and a strong acid solution. They added the metal to the acid, and noted any observations before they were asked to relate what they were observing to what they had been taught in the PowerPoint presentation. On completion of these tasks, the results sheet was collected from the pupils. They were then provided with an assessment sheet to complete in a given time. After the assessment was completed the pupils were brought together and the teaching facilitators discussed the results of the practical.

Chemistry Assessment:

This assessment comprised 10 questions divided into two parts. Part 1 (Questions 1-7) addressed factual-based questions about information presented in the practical requiring a basic level of conceptual understanding. Part 2 (Questions 8-10) assessed conceptual understanding of the material presented in the practical requiring the participant to work out and solve problems based on information learned. The assessment had acceptable levels of internal consistency as evidenced by Cronbach's alpha = 0.6 (Hair et al, 2006; see Appendix 1 for full list of questions).

Participants completed the BPVS first followed by the cognitive tasks and took part in the chemistry teaching session, practical and related assessment on a separate day approximately three weeks later.

Statistical Analyses

One key outcome measure from each CANTAB test was used in analysis. Namely: the total Between Search Errors for the Spatial Working Memory test; the Problems Solved in Minimum Number of Moves for the Stockings of Cambridge test; the Stop Signal Reaction time from the Stop Signal Task; and the Stage Reached Score for the ID/ED. These four outcome measures have been described as key measures within a wealth of research studies including those with child samples (e.g. Curtis et al., 2002; Luciana & Nelson, 1998; Rhodes et al., 2005). With a sample of 56 participants, the use of four key measures was within the recommended guidelines for sufficient power to detect significant effects within a regression analysis (Tabachnick & Fidell, 2007), although we should note that as we introduce two further predictor variables our sample size becomes less advantageous.

The dependent variables in analysis were the total score on part 1 (factual) and part 2 (conceptual) of the chemistry assessment and % correct in the generic science assessment. Age and score on the BPVS were employed as covariates.

In order to assess relationships between the key measures of executive function and the study specific chemistry assessment and grade achieved on the recent science class test, Pearson correlation analyses were conducted. Separate hierarchical linear regression analyses were also conducted for each of the two science assessments and the generic science grade. Age and BPVS score were entered in the first step with the key outcome measures for each of the four executive function tasks entered simultaneously in step 2.

Results

Mean scores and standard deviations for the science achievement test, chemistry assessment, BPVS and all tasks of executive function are illustrated in Table 1. While the mean science achievement test score for girls (70.33, SD = 16.30) was higher than for boys (66.74, SD = 17.48), this was not a statistically significant difference; therefore participants were treated as one group for all subsequent analyses.

Executive Functions and Chemistry Assessment

Correlational Analyses

Correlational analysis between performance of Part 2 of the chemistry assessment which required conceptual understanding revealed a significant correlation between performance on this assessment and total Between Search Errors on the Spatial Working Memory task ($r = -.43$, $p < 0.001$). There was also a significant relationship between Part 2 chemistry performance and the number of Problems

Solved in the Minimum Number of Moves on the SOC planning task ($r = .28$, $p < 0.05$).

Regression Analyses

A hierarchical linear regression analysis conducted with chemistry performance Part 1 (factual part) as the dependent variable and BPVS score, age and the four key measures of executive function as predictors revealed no significant model ($p > .05$). A hierarchical linear regression analysis was performed with each executive function measure entered simultaneously to predict performance of the chemistry assessment Part 2 (conceptual part), with age and BPVS score entered in step 1. BPVS score was a significant predictor of conceptual chemistry score in the first step of the model [$F (2, 52) = 11.50$, $p<0.001$, $\beta = 0.57$, $p<0.001$). In step 2 with all predictors entered in the model, a significant model emerged overall: [$F(6, 48) = 6.57$, $p <0.001$]. This model explained 38% of the variance in chemistry Part 2 performance (Adjusted $R^2 = 0.38$). While BPVS score remained a significant predictor, SWM Between Search Error score was also a significant predictor ($\beta= -.33$, $p<0.001$). In addition, ID/ED Stage Reached score approached conventional levels of statistical significance ($\beta= .22$, $p = 0.055$). See Table 3 for details of the final model.

Executive Functions and generic science grade

Correlational analyses

Pearson correlations were conducted between key outcome measures from each of the four executive function tasks and science grade achieved (see Table 1). Science grades were significantly correlated with the total number of between search errors on the SWM task ($r= -.31$, $p<0.05$.

Linear regression analysis

A multiple linear regression analysis was performed with age and BPVS entered in step 1 and each executive function measure entered simultaneously in step 2 to predict science grades. A significant model emerged in step 1 [F (2, 50) = 6.07, p<0.01] which accounted for 16% of the variance in science grades. BPVS score significantly predicted science score (β = .45, p<0.01). In step 2, with all executive function predictors entered in the model, a significant model emerged [F(4, 46) = 3.35, p<0.01]. This model explained an additional 11% of the variance (R^2 change = 0.11). None of the executive function measures predicted science grades in this model. See Table 2 for details of the final model.

Discussion

This study reveals that science grades and conceptual understanding of chemistry are significantly related to working memory. Performance on a visuo-spatial working memory task was predictive of conceptual understanding of chemistry when other aspects of executive functions were controlled for. This finding builds on previous research by confirming the role of visuo-spatial working memory in science learning. Importantly, the current study builds on previous findings in showing that visuo-spatial working memory was specifically predictive of conceptual and not factual learning of chemistry.

The current findings support and build on St-Clair Thompson & Gathercole (2006) who reported significant relationships between science achievement and both visuo-spatial working memory and inhibition. The current study reports that visuo-spatial working memory both correlates with and predicts science learning and emphasises the role of this function in effective learning. Both St-Clair Thompson & Gathercole (2006) and Latzman et al. (2010) reported a relationship between inhibitory control and science learning. In the current study inhibition was not significantly related to r the generic science class test, which required problem solving, the factual chemistry assessment which assessed memory for knowledge acquired, or the conceptual part of the chemistry assessment which required the pupils to apply the knowledge they had gained to solve problems. All three studies included samples of a similar age which would not therefore explain the differences in findings reported. It is possible that by the time of early adolescence aspects of inhibitory control that are important to particular types of science learning, such as those shown in learning chemistry as reported here, are mature. Further research with younger pupils, exploring different aspects of inhibition, and examining science specific disciplines, is warranted to clarify the role of inhibition in science learning.

Only one previous study has addressed the role of cognitive planning in science learning where it was shown to be important for both factual and conceptual learning of biology (Rhodes et al., 2014). The current findings show a modest correlation between planning and conceptual learning of chemistry but this was not found to predict performance on any of the 3 science assessments we included. The Rhodes et al. (2014) study was similarly powered so this difference in findings may reflect discipline specific effects .The findings also do not concur with previous reports of a role for attention set-shifting in science achievement (Latzman et al., 2010). Power issues may have played a role here as suggested by the marginally non-significant finding of a predictive relationship between performance on the attention shifting task (ID/ED Stage Reached score) and the conceptual learning assessment. The current findings support previous research that has highlighted the role of executive/strategic aspects of cognitive functioning in academic learning (e.g. Bull and Scerif, 2001; Clair-Thompson and Gathercole, 2006; Daneman and Carpenter, 1980) and highlights the need for further research in a range of science disciplines in this area.

A number of aspects of the study design may have limited the findings reported in the current study. To avoid confounding with executive function skills we used the BPVS as a measure of general verbal ability rather than including an IQ test. The findings therefore need to be interpreted in light that we have not controlled specifically for IQ within the analyses. While we examined a broad range of aspects of executive function, we did not include any verbally-loaded executive function tasks. The findings reported here, which are specific to working memory, may have extended to other aspects of executive function had we included verbally-loaded executive function tasks. Future research should determine if broader aspects of executive function predict science learning when verbal-based tasks are employed. None of the executive function tasks predicted performance on the generic science test above language ability (BPVS scores), suggesting the science test mostly implicated language rather than wide cognitive abilities. Spatial Working Memory performance predicted achievement on the conceptual chemistry assessment over and above the impact of language ability suggesting that this task assessed a broader range of abilities. The study also had a modest sample size and with borderline non-significant results it may have been under-powered to detect broader executive function effects. Rhodes et al. (2014) had the same level of statistical power though and reported a broader range of findings in relation to learning factual and conceptually assessed biology. Together the studies suggest that there may be discipline specific factors relating to the relationship between executive functions and learning science.

The current study has a number of implications for teaching science. The existing literature shows that children at the onset of adolescence are in general not at adult levels of cognitive performance on executive function tasks (e.g. Anderson et al., 2001). Importantly, visuo-spatial working memory was predictive of performance on a conceptual learning assessment. The pupils in the current study had been attending secondary level education for 18 months and were enrolled in a number of discipline specific science classes during this time. The current findings suggest that during early adolescence, science learning should be tailored to accommodate developmental restrictions in working memory processes to ensure optimal learning. There is some recent evidence that tailored working memory interventions may improve mathematics learning in the classroom in children with poor working memory (Holmes, Gathercole & Dunning, 2009). St-Clair-Thompson, Stevens, Hunt & Bolder (2010) also reported improvements in working memory following working memory training, but found that these improvements did not extend to academic learning assessed five months after training (St-Clair-Thompson, Stevens, Hunt & Bolder, 2010). The authors concluded that the standardised tests used may not, however, have particularly loaded working memory. The current findings suggest the possibility that a targeted intervention on discrete aspects of executive functioning may improve science learning.

The current findings build on existing research showing that visuo-spatial working memory predicts performance on a conceptual but not a factual chemistry assessment highlighting that executive functions may be implicated when children have to apply the knowledge they have learned. Science learning and achievements in early adolescence may be related to developmental differences in the development of executive functions.

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Table 1

Means (SD) and Correlational Data for Key Measures

Measure (n)	Mean (SD)	1	2	3	4	5	6	7
1) % Correct Science Grade (54)	69.14 (16.91)							
2) Chemistry Part 1 (Facts) (56)	69.21 (14.16)	.05						
3) Chemistry Part 2 (Conceptual) (56)	47.77 (21.88)	.52***	.33*					
4) BPVS (56)	94.98 (11.57)	.41**	.21	.56***				
5) Working Memory SWM BS Errors (55)	27.85 (13.75)	-.31*	-.22	-.43**	-.26			
6) Planning SOC Minimum Moves (56)	8.18 (2.02)	.23	.03	.28*	.19	-.23		
7) Inhibition SSRT (56)	210.19 (73.04)	-.16	-.25	-.11	-.23	.01	-.14	
8) Attention Set-shifting ID/ED Stage Reached (56)	8.57 (0.81)	.15	.07	.20	.11	.16	.06	.02

*Note:** indicates significance at $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table 2
Regression data: gives information for the predictor variables entered into the model for science generic exam grade.

		B	*SE* B	β	95% CI
Step 1	Age	11.36	6.41	0.24	-1.50 to 24.23
	BPVS	0.66	0.19	**0.45****	0.27 to 1.05
	R^2	.20*			
Step 2	Age	13.80	6.43	**0.29***	0.97 to 26.74
	BPVS	0.49	0.20	**0.33***	0.09 to 0.89
	ID/ED	4.10	2.63	0.20	-1.19 to 9.39
	SOC	0.82	1.07	0.10	-1.33 to 2.97
	SWM	-0.28	0.16	-0.24	-0.61 to 0.04
	SSRT	-0.03	0.03	-0.13	-0.09 to 0.03
	R^2 change	.11			

*Note:** indicates significance at p<0.05, ** p<0.01, *** p<0.001. SWM = the total Between Search Errors for the Spatial Working Memory test; SOC = Problems Solved in Minimum Number of Moves for the Stockings of Cambridge test; SSRT =the Stop Signal Reaction Time from the Stop Signal task; ID/ED = Stage Reached Score for the ID/ED. N = 53.

Commented [t1]: To the Editor: You asked if this was statistically significant: it is not.

Table 3
Regression data: gives information for the predictor variables entered into the model for the chemistry conceptual assessment.

		B	*SE* B	β	95% CI
Step 1	Age	4.27	7.46	0.07	-10.70 to 19.23
	BPVS	1.08	0.27	**0.57*** **	0.63 to 1.53
	R^2	.31***			
Step 2	Age	6.58	7.12	0.10	-7.73 to 20.90
	BPVS	0.85	0.23	**0.45*** **	0.40 to 1.31
	ID/ED	5.98	3.04	0.22+	-0.14 to 12.09
	SOC	1.05	1.22	0.10	-1.40 to 3.50
	SWM	-0.53	0.19	**-0.33** **	-0.90 to -0.16
	SSRT	-0.01	0.03	-0.01	-0.07 to 0.07
	R^2 change	.14*			

*Note:** indicates significance at $p<0.05$, ** $p<0.01$, *** $p<0.001$; + $p = 0.55$. SWM = the total Between Search Errors for the Spatial Working Memory test; SOC = Problems Solved in Minimum Number of Moves for the Stockings of Cambridge test; SSRT =the Stop Signal Reaction Time from the Stop Signal task; ID/ED = Stage Reached Score for the ID/ED. N = 55.

Questions – Acids and Alkalis

Factual

1. Does a low pH (e.g. 2) indicate the presence of an acid or an alkali base?
____

2. When an acid and an alkali are reacted together what molecules are formed?
____

3. What gas is given off when metals are reacted with acids? What else is also made?
____

4. What is the highest pH that an alkali can have?
____

5. Did the apple juice and apple slice have different pH? If they are different can you suggest a reason why?
____
____

6. Name two household items that are acidic and two household items that are basic.

_____________ _______________
_____________ _______________

7. What is the pH of (circle the correct answers):

Blood serum?	5.5-6.5	7.35-7.45	9.0-9.5
Stomach fluids?	1-3	4-5	5-6
Saliva?	4-5.5	6.0-7.5	11-12.5

Conceptual

8. When 5 mL of an acid solution and 5 mL of an alkali solution are added together, what do you think the pH of the solution will become and why?
____
____
____
____
____

9. If 10 mL of vinegar with a pH of 1 is added to a normal sized bath full of water, what will the pH of the bath water become and why?
____
____
____
____
____

10. Factory and household pollution is sometimes known to cause a phenomenon known as "acid rain". Two of the major pollutants that cause this are the gases sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). Can you suggest a reason for why these create acid rain?
____
____
____
____
____
____