Abstract

Recent educational reports highlight the need to improve literacy and science learning in secondary education, with particular concern for Key Stage 3 pupils (12-14 years). To explore the importance of achieving text cohesion as a science skill we conducted two experiments in which we measured on-line (reading times) and offline (comprehension accuracy) for texts that were high and low cohesion. In study one \( (n=60) \) we manipulated referential cohesion by using noun-repetition (high cohesion) and synonymy (low cohesion). Students showed enhanced comprehension accuracy and faster comprehension responses for text that were high in referential cohesion. In study two \( (n=52) \) we examined the use of connective text designs (‘because’, ‘and’ and ‘no connective’). Students demonstrated enhanced reading times for text using a ‘because’ connective. Additionally, we examined the importance of individual differences (reading ability, science self-concept and self-esteem) as predictors of achievement with science comprehension tasks. Across both experiments reading ability was a unique predictor of comprehension with both high (noun repetition text and ‘and’ text) and low cohesion text (synonym text and ‘no connective’ text). These findings highlight the importance of achieving text cohesion for promoting science comprehension and learning, as well as the significance of reading ability in determining levels of comprehension and learning in science.

Keywords: referential cohesion, connective cohesion, reading comprehension, science learning
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Introduction

It is widely recognised that understanding the process of science text comprehension needs greater attention, particularly with regard to informing educational policies and teaching practices in the United Kingdom (Parliamentary Office of Science & Technology, Postnote, 2009) and United States (Council of Chief State School Officers & National Governors Association, 2010). The product of high level reading comprehension is a coherent mental representation of the text arguments in which individual sentence meanings are integrated to form a global meaning (Kintsch, 1998; Johnson-Laird, 1980). However, texts rarely state all the relevant information to the situation, therefore, to link sentences together the reader must make an inference to fill in the missing information and to create a coherent representation (Zwaan & Singer, 2003). For example, to connect the sentences ‘Jill ran into the house. It started to rain’, the reader must infer a causal connection as the text does not provide this information (e.g., by using ‘because’). Recent text analyses have revealed that causal cohesion is one of five major factors that underlie text difficulty, and in comparison to language arts and social studies, causal cohesion is particularly low in science text (Graesser, McNamara, & Kulikowich, 2010).

Causal cohesion can be increased by the use of connectives devices, such as ‘because’ and ‘and’ which signify the relation between events and clauses (Degand & Sanders, 2002; Sanders & Noordman, 2002). Appropriate connectives have been shown to improve reading times, memory for text and inference making for adult readers (e.g., Ferstl & von Cramon, 2001; Murray, 1997). According to the connective-elicited inference hypothesis elaborative inferences are generated to a greater extent when sentences are joined by a connective compared to no connective, this process results in slower end of clause reading times (Millis,
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Golding, & Barker, 1995). However, according to the connective-resource saving hypothesis, the presence of a connective provides specific information of the relationship between adjacent sentences, reducing the need for costly inferences, which can result in faster end of clause reading times (Degand, Lefevre, & Begston, 1999).

A second major factor underlying text difficulty is referential cohesion (Graesser et al., 2010). Referential cohesion is observed when a noun, noun-phrase or pronoun refers to another word within the text (e.g., ‘a man’ in sentence one is referred to as ‘the man’ in sentence two). An inference needs to be made when synonyms (a word that means the same, or nearly the same, as another word) are used to refer to concepts (e.g., ‘a man’ is later referred to as ‘Steve’). Repetition of referential phrases has been shown to improve comprehension and reasoning processes (Bouquet & Warglien, 1999; Walsh & Johnson-Laird, 2004). Measures of reading time show that words are processed faster on subsequent presentations (repetition priming) (e.g. Jacoby & Dallas, 1981; Rugg, 1985). Establishing a new referent (e.g., a synonym) results in delayed comprehension compared to using an already established referent, indicating that the more referents that are included into the mental model of text the more difficult the comprehension process (Murphy, 1984).

Analyses of science textbooks reveal that text design is often low in the use of overt cohesion markers (Beck, McKeown, Sinatra, & Loxterman, 1991), as such an important part of the process of understanding text in these books will involve making effortful and time-consuming inferences to establish connective and referential links. Research with college-aged students and adults shows that readers experience comprehension difficulty when cohesion markers are not included in text, and that increasing text cohesion in expository text (e.g., science text), by replacing pronouns, adding connectives and increasing conceptual overlap improves comprehension (McNamara & Kintsch, 1996; Ozuru, Briner, Best, & McNamara, 2010; Ozuru, Dempsey, & McNamara, 2009) and shortens reading times
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(McNamara & Kintsch, 1996; O’Brien, Rizzella, Albrecht, & Halleran, 1998). Evidence also suggests that similar effects can be observed in children’s reading of narrative text (Cain, 2003; Cain & Nash, 2011). However, few studies have explored the effects of cohesion markers in science text with school aged children and typically report no significant benefits of increased text cohesion (Best, Ozuru, Floyd, & McNamara, 2006; McNamara, Ozuru, & Floyd, 2011). Nonetheless, a study by McNamara, Kintsch, Songer and Kintsch (1996) did report beneficial effects of high cohesion science text on young science students’ comprehension. Their study modulated text cohesion in terms of one clear strategy (by providing additional information to identify that subtopics in the text were talking about traits of mammals), as opposed to employing multiple cohesion manipulations, which is typical of the design employed in the aforementioned studies. Therefore, these results provide promise for continuing the investigation of science comprehension and text cohesion by manipulating singular cohesion devices in larger student samples. Additionally, studies exploring text cohesion in children’s science reading have focussed upon the product of text design (comprehension assessed through short and long answer questions) and not the online process which can be evidenced through reading times. To further our understanding of text cohesion and science reading comprehension it is essential that we explore these measures.

Learning in the science classroom is also likely to be mediated by individual differences. In line with Social Cognitive Theory (SCT), science learning is likely to be shaped by cognitive factors and behavioural factors, associated with previous experiences and observations (Bandura, 1977). A fundamental cognitive factor related to text comprehension is reading skill (e.g., Gough, Hoover, & Peterson, 1996; McNamara, 2009). This includes both basic decoding skills that enable the reader to identify the words on the page and also higher level comprehension skills that enable readers to make sense of sentences and to relate concepts from different parts of the text using inferential processes (Daneman & Hannon,
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2001). By establishing the relationships between concepts from different parts of the text, readers can form a cohesive representation of the text. Therefore it may not be surprising to find a strong and fundamental relationship between reading skill, text cohesion and subsequent comprehension when reading about science. Indeed, evidence suggests that basic reading skills (word decoding and vocabulary) are strongly related to children’s reading comprehension (Catts, Adolf, & Weismer 2006; Cain & Oakhill, 2004). Moreover, the nature of the relationship between reading and comprehension may be mediated by text design, such that only skilled readers are thought to benefit from reading high cohesion texts (Ozuru et al., 2009; O’Reilly & McNamara 2007). It is possible that this effect occurs because high cohesion text is by nature more dense (due to increased explanations and elaborations) and contains longer sentences (due to increased linking of shorter sentences when connectives are used) which necessitates stronger reading skills (Beck et al. 1991; Ozuru et al., 2009). To date the relationship between reading ability and text cohesion has not been determined in secondary school-aged children. Yet this may prove crucial to developing strategies for facilitating science learning from different science texts (i.e. those that are of high and low cohesion).

An inherent and well-established component of learning from previous experiences and observations is an individual’s perceptions of task competence (Bandura, 1977). These perceptions are often conceptualised in terms of ‘self-esteem’ and ‘self-concept’. Self-esteem can be viewed as an individual’s overall evaluation of their own worth. However, research has shown only a moderate relationship between general self-esteem and academic achievement (e.g., Byrne, 1984; Marsh & Yeung, 1998; Valentine, Dubois, & Cooper, 2004). It is thought that this is because general self-esteem is a largely unspecific concept that does not account for the multi-dimensional construct of feelings of self-worth, including academic specific self-concept (Pullman & Allik, 2000; Shavelson, Hubner, & Stanton, 1976).
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Therefore, we also considered the role of academic (science) self-concept in our research. Academic self-concept can be defined as an evaluative self-perception created through the students’ school based experiences and their interpretations of these experiences (Marsh & Craven, 1997). It remains contentious as to whether self-concept determines academic achievement or whether self-concept is a consequence of achievement. However, these are perhaps best viewed as in terms of a reciprocal effects model (see Marsh, Byrne, & Yeung, 1999). Positive self-perceptions are associated with greater motivation and perseverance to achieve tasks (e.g., Crothers, Hugh, & Morine, 2008) which may prove important in achieving text cohesion, especially from more difficult text designs, such as low cohesion text. Indeed, competence perceptions have demonstrated a specific relation to science achievement (Wang, Oliver, & Staver, 2008), and reading comprehension (Katzir, Lesaux, & Kim, 2009), but have yet to be examined in terms of comprehension of science text cohesion.

Our recent investigations show that high cohesion text can improve secondary school students learning from science text, and that this learning is mediated by a range of individual differences, including reading ability (Hall, Kowalski, Paterson, Basran, Filik, & Maltby, 2014; Hall, Basran, Paterson, Kowalski, Filik, & Maltby, 2014). However, these studies used measures of offline comprehension (i.e., comprehension accuracy) only, and not online measures (i.e., reading times) that are informative about the process of comprehension. Additionally, this previous modulated global text cohesion and did not investigate the effects of local cohesion ties (i.e., causal connectives and referential cohesion). Given these findings, and those that suggest a strong link between reading skill and science comprehension in children (e.g., Best, Rowe, Ozuru, & McNamara, 2005; Ozuru et al., 2009) we aimed to specify the nature of this relationship more precisely. To do this we explored whether text cohesion influences online reading processes, or just the product of reading (comprehension) in secondary school children, and whether reading skill and other individual differences
determine reading of high and low cohesion science text during reading (online measures) or post reading (comprehension).

**Aims of the Study**

Our research examined the role of text cohesion for reading and learning about science by investigating the role of connective and referential expressions in science text comprehension by secondary school students. We measured the time taken to read science texts designed to be either high or low in cohesion along with the accuracy and latency of response times for follow-up questions designed to assess students’ comprehension. With reference to the Coh-Metrix paradigm (McNamara, Louwerese, McCarthy, & Graesser, 2010) we focussed on two important aspects of text cohesion. The first experiment explored the influence of noun-repetition and synonymy (referential cohesion) on students and the second experiment assessed the importance of connective devices ‘because’ and ‘and’. In both studies we examined the relationship between academic individual differences (which have previously been identified as being important determiners of learning) and students’ comprehension performance with high and low cohesion science texts. In particular, we were concerned with investigating the potential of individual differences as predictors of science comprehension. Reading and writing attainment at Key Stage 3 has been identified as a particular problem (Ofsted, 2012), therefore we focused our investigations on this age-group (12 – 14 years).

**Study 1: Referential Cohesion**

To examine whether referential cohesion modulates secondary school students’ comprehension of science text we measured students reading times and comprehension performance of text that was designed to be high or low in referential cohesion. High cohesion text (*noun-repetition*) replicated the target referent across three sentences and in the
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comprehension question. Low cohesion text (synonym) used a synonym to refer to the noun-phrase in the first sentence (e.g., ‘an enzyme’ in the first sentence was later referred to as ‘a protein’). To investigate potential predictive effects of individual differences in the comprehension of co-reference we examined whether reading ability, science self-concept and self-esteem predicted performance on measures of comprehension via regression models.

Method

Participants

Sixty students (30 males, 30 females) from mixed ability schools in the East Midlands of the UK took part in the study. Ages ranged from 11 years 3 months – 12 years 5 months, with a mean age of 12.4 years ± 0.4 (mean ± standard deviation). Written permission was obtained from the head of the school. Parents were fully informed of the study and gave fully informed consent for their child to take part in the experiments during school time. Testing procedures complied with the BPS Ethics Code of Conduct (2009).

Apparatus & Materials

The text was programed via E-Prime 2.0. All text was presented using Bold Courier New, size 14 font. The main text was displayed using black font and the question using navy font. The feedback was presented in blue font for a correct response and red font for an incorrect response. The text was viewed by the students using an ‘hp ProBook 6560b’ laptop, they recorded their responses on the keypad by pressing ‘Z’ for yes and ‘M’ for no.

Text. Forty trials were created based upon text in General Certificate of Secondary Education (GCSE) science text books (Gadd, 2005), 20 of the trials were displayed in the noun-repetition condition (high cohesion), and 20 in the synonym condition (low cohesion); (1) Noun-repetition condition: referential cohesion was maintained by directly repeating the noun-phrase in the three sentences and in the comprehension question (see Figure 1). (2)
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*Synonym condition:* the noun-phrase used in the first sentence (e.g., plastic) was replaced by a more general referent (e.g., polymer) in the second and third sentence. To ensure consistency throughout the stimuli in this condition the first referent was always a specific noun-phrase for a more general referent later used. So that the two conditions only differed by the use of a synonym, the referent in the second and third sentences were those used consistently in the noun-repetition condition. The comprehension question was designed to assess whether the student had linked the target referent in the sentences. The question was specifically based upon the content of the third sentence (see Figure 1 for an example). Half of the questions were correctly answered by a ‘yes’ response and half with a ‘no’ response, in both conditions.

The texts were taken from the three core areas of secondary school science; biology (20 trials), chemistry (11 trials) and physics (9 trials). Two versions were created, so that the noun-repetition trials (high cohesion) in version 1 were shown as synonym trials (low cohesion) in version 2, and vice versa. The order of presentation of correct ‘yes’ and correct ‘no’ responses, and noun-repetition and synonym text was randomised.

[Figure 1 about here]

**Reading ability – Nelson-Denny Reading Test.** The vocabulary component of this well established test was used to assess participants reading ability (Brown, Fisco, & Hanna, 1993). Participants read the beginning of a sentence and were asked to choose which one of five words they felt best completed the sentence. For example, *‘flexible means a) liveable b) bendable c) fixable d) fragile e) fused’*. The vocabulary section has been used in similar research (Ozuru et al., 2009) and has excellent internal reliability (α = .90, Ozuru et al., 2009). The test has been shown to be a good predictor of academic success (Collins & Onwuegbuzie, 2002; Hawes, Heerman, Lamb, Lowenstein, & Seltzer, 1982; Wood, 1982).

**Rosenberg Self-Esteem - Scale.** Self-esteem was measured by the Rosenberg Self Esteem Scale (RSES; Rosenberg, 1965). This is a 10 item self-report scale, whereby
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participants rate each statement on a four point scale (from strongly agree to strongly disagree). The RSES has good scores for validity (Tinakon & Nahathai, 2012), with high Cronbach’s alpha scores of internal consistency ($\alpha = .88$) and strong correlations with other measures, such as the single item scale (Robins, Hendin, & Trzesniewski, 2001). The RSES also has good test-retest scores of typically .82 to .86 (Blascovich & Tomaka, 1993; Rosenberg, 1986).

Science Self-Concept – ASDQI. The ASDQI was designed to measure secondary school students’ self-perceived academic competence (Marsh, 1990a, 1990b, 1993). From the original 14 scales only the one pertaining to self-concept in science was chosen for (e.g. I get good marks in science classes; I learn things quickly in science). Six statements were evaluated on an eight-point scale as to how well the participant thought it reflected themselves (1 = definitely false, 8 = definitely true). Previously reported reliability measures for each scale are high ($\alpha = .88 - .94$). Scores on science self-concept and academic achievement show good correlation (.70) (Marsh, 1992).

Procedure

The individual difference tests were administered to the students as a whole class. The students were taken through the instructions for the reading test, including the practice questions, before being allotted 15 minutes to answer as many questions as they could on form H. No time restraints were set for completing the self-esteem scale or the ASDQI. All tests were completed in silence.

The reading task was conducted on a one-to-one basis with each student, in an empty classroom on a separate day from the individual difference tests. The student was informed that we needed their help to find ways to improve how science textbooks are written. Verbal instructions for completing the task were given prior to written instructions. The student was
re-assured that they could ask any questions if the instructions were not clear, and at any time during the experiment. All students were competent with the task after completing the practice trials. Every trial started with the instruction to ‘press any key to begin’. The sentences were displayed on the screen in isolation (see Figure 1). After reading one sentence the students pressed the space bar, the sentence then disappeared and was replaced by the next one in the sequence. Once the question had been answered the feedback screen was displayed for three seconds, indicating whether or not the correct response had been chosen. The next trial then started with the ‘press any key to begin’ instruction. Once all trials had been viewed a thank you message was presented to signal the end of the experiment.

Data Analysis

To prevent data distortion we assessed whether students’ performance on the reading tests were less than and/or greater than 2.5 standard deviations from their individual mean for each sentence (dependent variable of reading times). However, no student met this exclusion criterion for any sentence reading time. Analysis of reading data was conducted using Paired samples $t$-tests. Only trials where the students correctly responded to the comprehension question were included. Analysis of individual differences was conducted on the two key measures of comprehension; total number of correctly answered questions ($Comprehension$) and response time to correctly answering the question ($Question \ response \ time$).

Results

Reading Data

To investigate whether referential cohesion modulated students comprehension of science text, analysis was conducted on (1) Comprehension accuracy, (2) Question response time, (3) Reading time to sentence 1, (4) Reading time to sentence 2, (3) Reading time to
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sentence 3. To ensure there was no difference in difficulty between the two versions of the text (see Materials) a one-way ANOVA was conducted, with number of correct responses as the dependent variable and version as the factor, no significant difference emerged \( F(1, 59) = .829, p > .05 \).

Comprehension accuracy differed significantly across the two conditions \( (F(1, 59) = 7.66, p < .01, \eta_p^2 = .12, \) see Table 1), with a greater number of correct answers for noun-repetition text (85% correct performance) than synonym text (80% correct performance). Question response time also differed significantly across the two conditions \( (F(1, 59) = 10.51, p < .01, \eta_p^2 = .15) \), with faster response times for noun-repetition text (3910ms ± 128) than synonym text (4100ms ± 121). No significant reading time differences were observed for sentences in the high and low cohesion texts (sentence 1, \( F(1, 59) = .004, p > .05 \), sentence 2, \( F(1, 59) = .031, p > .05 \), or sentence 3, \( F(1, 59) = .603, p > .05 \)).

[Table 1 about here]

**Individual Differences as Predictors of Text Comprehension**

Cronbach’s alphas were calculated to determine that the individual difference tests used had adequate internal reliability. The individual difference scales obtained adequate reliability scores \( (\alpha \geq .64; \) see Table 1). To investigate whether reading ability, self-esteem and science self-concept correlated with measures of reading comprehension a Pearson correlation was conducted (see Table 2). Reading ability significantly positively correlated with comprehension accuracy with noun-repetition and synonym text. Reading ability significantly negatively correlated with question response time with noun-repetition and synonym text. Science self-concept significantly positively correlated with comprehension accuracy of synonym text, and significantly negatively correlated with question response time to noun-repetition text. This illustrates that reading ability correlates with higher
comprehension accuracy and faster question response times; therefore, higher reading ability is associated with better science text comprehension for high and low cohesion designs.

Two-step hierarchical regression models were conducted to examine which of these individual difference variables could uniquely predict comprehension performance. We conducted the regression models separately for noun-repetition and synonym text designs in order to potentially reveal different individual difference predictor effects for sound science comprehension. As reading ability was considered to be of greatest theoretical and practical importance, scores on the Nelson-Denny reading test were entered in Step 1. In Step 2 measures of self-esteem and science self-concept were added. Across all regression models Variance Inflation Factors (VIF) for the predictor variables ranged from 1.00 – 1.06, below the threshold values (VIF of 10, or at least of 4) that used to suggest collinearity between the predictor variables (Kutner, Nachtsheim, Neter, & Li, 2004).

**Comprehension accuracy.** Analysis of comprehension performance with noun-repetition text (Table 3) showed that in Step 1, reading ability was a significant predictor of comprehension accuracy \(r = .49, r^2 = .24, \text{adj } r^2 = .23; F(1, 58) = 18.31, p < .001\). In Step 2, the inclusion of self-esteem and science self-concept also produced a significant model \(r^2\) change = .01, \(F\) change (2, 55) = .17; \(r = .49, r^2 = .25, \text{adj } r^2 = .21; F(3, 58) = 6.04, p < .01\). Reading ability demonstrated a significant positive regression coefficient, illustrating that higher reading abilities are associated with better comprehension of science text that uses noun-repetition.

Comprehension performance with synonym text (Table 4) showed that in Step 1, reading ability significantly predicted comprehension \(r = .33, r^2 = .11, \text{adj } r^2 = .10; F(1, 58) = 6.71, p < .01\). In Step 2 a significant model also emerged \(r^2 \) change = .08, \(F\) change (2,
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55) = 2.73; \( r = .43, r^2 = .19, \) adj \( r^2 = .14; F(3, 58) = 4.19, p < .01 \). Reading ability and science self-concept were significant positive regression coefficients. Therefore, both a higher reading ability and a greater science self-concept are important predictors of comprehension of science text that uses synonyms.

[Tables 3 & 4 about here]

**Question response time.** With question response time as the dependent variable, performance with noun-repetition text (Table 5) showed that in Step 1, reading ability significantly predicted performance (\( r = .55, r^2 = .30, \) adj \( r^2 = .29; F(1, 58) = 24.94, p < .001 \)). In Step 2, the inclusion of science self-concept and self-esteem produced a significant model (\( r^2 \) change = .032, \( F \) change (2, 55) = 1.32; \( r = .58, r^2 = .33, \) adj \( r^2 = .30; F(3, 58) = 9.29, p < .001 \)). However, only reading ability demonstrated a significant negative regression coefficient, indicating that only reading ability is a key predictor for faster comprehension response times after reading science text that uses a noun-repetition design.

Response time with synonym text (Table 6) showed that in Step 1, reading ability significantly predicted performance (\( r = .53, r^2 = .28, \) adj \( r^2 = .268; F(1, 58) = 22.27, p < .001 \)). Step 2, incorporating science self-concept and self-esteem, also produced a significant model (\( r^2 \) change = .01, \( F \) change (2, 55) = 1.84; \( r = .54, r^2 = .28, \) adj \( r^2 = .25; F(3, 58) = 7.33, p < .001 \)), however, only reading ability produced a significant negative regression coefficient. This suggests that reading ability alone is a predictor for quicker comprehension response times after reading science text that uses a synonym design.

[Tables 5 & 6 about here]

**Summary**
Students demonstrated enhanced comprehension (higher percentage of correctly answered comprehension questions) of science texts when the texts used a noun-repetition design compared to those that used synonyms to refer to nouns. The students were also faster at correctly answering the comprehension question after reading text that used noun-repetition. No significant effects of reading times were observed between noun-repetition and synonym text designs. Higher reading ability predicted greater comprehension accuracy and faster responses to the comprehension question with both the noun-repetition and synonym text design. Higher science self-concept predicted better comprehension of synonym text. This suggests that sound reading skills are important determiners of secondary school students’ comprehension of science text when the text uses both noun-repetition and a synonym design. It is possible that the effect occurs because reading skills enhance the readers’ ability to deal with the denser text associated with the noun-repetition design (Ozuru et al., 2009) and enable the reader to make the links between the sentences to connect the synonyms (e.g., McNamara, 2009). High science self-concept showed as an important predictor of students’ science comprehension abilities with synonym text, but not noun-repetition text. This suggests that when the task is more difficult students that have a stronger belief in their scientific abilities are more likely to succeed.

**Study Two: Connective Cohesion**

To investigate the effects of connectives on students’ comprehension of science we analysed comprehension performance (question accuracy and reading times) to text designs using a causal connective ‘because’, the additive connective ‘and’ or a full stop ‘no connective’. Given the potential significance of reading ability and science self-concept in study 1, we further investigated the potential of these reader-related factors in predicting science comprehension.

**Method**
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With the exception of the text design, all materials and procedures were identical to that used in study 1.

Participants

Seventy one students (45 males, 26 females) from mixed ability secondary schools in the East Midlands, UK, took part in the study. The participant’s ages ranged from 11 years 3 months – 12 years 4 months (11.5 years ± .4). Written permission was obtained from the head of the school. Parents were informed of the study and gave fully informed consent for their child to take part in the experiments during school time. Testing procedures complied with the BPS Ethics Code of Conduct (2009).

Materials

Text. Forty-two trials were created based upon text in General Certificate of Secondary Education (GCSE) science text books (Assessments and Qualification Alliance [AQA] GCSE Science, Collins Education and Nelson Thornes Ltd). Each trial was composed of (A) two introductory sentences, which were not directly related to the inference. (B) One target sentence, composed of two meaningful stand-alone clauses, the two clauses were joined by ‘because’ (causal connective), ‘and’ (additive connective) or a full stop (no connective). There was a direct causal relationship between the two clauses, so that clause two directly caused clause one to occur. (C) A final sentence, unrelated to the inference was presented to help disguise the purpose of the target sentence. (D) An inference question designed to measure whether the student had made the connective inference between clause one and two in the target sentence. The inference question was presented so that half of the questions were correctly answered with ‘yes’ and half with ‘no’, in all three conditions (see Figure 2). The stimuli controlled for additional confounds, such that the use of pronouns was avoided, as was the inclusion of additional connectives other than that in the target sentence.
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Three sets of stimuli were created so that each trial was shown in each connective condition (causal, additive and no connective) across participants. The participants saw each trial only once; in total 14 trials for each connective condition were presented. The text pertained to the three domains of science commonly studied, biology (16 trials), physics (16 trials) and chemistry (10 trials). The three connectives were presented with equal likeliness within the three domains. The presentation of questions which were correctly answered with a ‘yes’ and ‘no’ response, and the connective condition were randomised.

[Figure 2 about here]

Results

Following the exclusion criteria used in study 1, the resulting data set consisted of 52 students (18 females) with an age range of 12 years 4 months – 11 years 5 months, and a mean age of 11.6 years ± .06. Repeated measures ANOVA was used on all reading data, with condition (3 levels) as a within subjects variable. Where appropriate the Greenhouse Geisser adjustment was used and post-hoc comparisons were applied in the form of pairwise comparisons with Bonferroni corrections. The analysis of reading data was conducted on trials where the students correctly responded to the comprehension question. Analysis of individual differences was conducted on the two key measures of comprehension; total number of correctly answered questions (Comprehension) and response time to correctly answering the question (Question response time).

Reading Data

To investigate whether the connectives used in science text modulated students’ reading and comprehension performance, analyses were conducted on four measures of reading and comprehension performance 1) Comprehension accuracy: the total number of
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Correctly answered comprehension questions, 2) Question response time: time taken to correctly answer the comprehension question, 3) Reading time prior to the connective: reading time of the sentence preceding (and including) the connective, sentence 3a (see Figure 2), 4) Reading time post connective: reading time of the sentence following the connective, sentence 3b.

(1) Comprehension accuracy did not differ significantly across the three connective conditions $F(2, 102) = 1.14, p > .05$ (Table 7). (2) Question response time did not significantly differ across the conditions $F(2, 102) = .62, p > .05$ (Table 7). (3) No significant difference in reading time prior to the connective showed that reading times were consistent across the three connective conditions $F(2, 102) = 2.39, p > .05$. (4) Reading time post connective was significantly modulated by the connective used in the sentence $F(2, 102) = 3.62, p < .04$, $n_p^2 = .06$, with faster reading times in ‘because’ sentences (3130ms ± 97) compared to ‘no connective’ sentences (3337ms ± 106) ($p < .02$). No other significant differences were observed.

[Table 7 about here]

**Individual Differences as Predictors of Text Comprehension**

Cronbach’s alphas were calculated to determine that the individual difference tests used had adequate internal reliability. The individual difference scales obtained good reliability scores ($\alpha \geq .75$) (see Table 7). To assess whether individual reading ability and science self-concept correlated with measures of reading comprehension a Pearson correlation was conducted. Reading ability significantly positively correlated with comprehension accuracy, performance with ‘and’ and ‘no connective’ texts and significantly negatively correlated with response time to correctly answering the question with ‘because’ and ‘no connective’ texts. Science self-concept significantly positively correlated with
question response time with ‘and’ text. Science self-concept also significantly negatively correlated with question response time with ‘because’ text (see Table 8).

Two-step hierarchical regression models were conducted to examine which of the individual difference variables could uniquely predict reading measures with the different causal connectives. Reading ability was entered in Step 1, and self-concept in Step 2. Across all regression models Variance Inflation Factors (VIF) for the predictor variables was 1.00, below the threshold values to suggest collinearity between the predictor variables (Kutner et al., 2004).

**Comprehension accuracy.** Analysis of comprehension performance with ‘and’ text (Table 9) showed that in Step 1, reading ability was a significant predictor of performance ($r = .34$, $r^2 = .11$, adj $r^2 = .09$; $F(1, 50) = 6.31, p = .01$). In Step 2, the inclusion of science self-concept also produced a significant model ($r^2$ change = .000, $F$ change $(1, 48) = .019; r = .34$, $r^2 = .11$, adj $r^2 = .08$; $F(2, 50) = 3.10, p = .05$), but only reading ability demonstrating a significant positive regression coefficient. This indicates that only reading abilities are unique predictors of a better science comprehension when the text uses appropriate additive connections between the sentences.

Comprehension performance with ‘because’ text (Table 10) showed that in Step 1, reading ability did not reach statistical significance as a predictor of performance ($r = .27$, $r^2 = .07$, adj $r^2 = .05$; $F(1, 50) = 3.79, p = .057$). In Step 2, the model was not statistically significant ($r^2$ change = .002, $F$ change $(1, 48) = .114, p = .74; r = .27, r^2 = .07$, adj $r^2 = .03$; $F(2, 50) = 1.92, p = .16$), although reading ability remained a significant coefficient. This suggests that stronger reading skills predict better science comprehension when the text uses appropriate because connections between the sentences.
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Comprehension with ‘no connective’ text (Table 11) showed that Step 1 produced a significant model \( (r = .29, r^2 = .08, \text{adj } r^2 = .06; F(1, 50) = 4.47, p < .05) \). In Step 2 the model was not statistically significant \( (r^2 \text{ change} = .01, F \text{ change} (1, 48) = .56, p = .45; r = .31, r^2 = .09, \text{adj } r^2 = .06; F(2, 50) = 2.50, p = .09) \), again, reading ability was maintained as a significant coefficient. This indicates that reading ability alone is a unique predictor of science comprehension when the text contains no connective devices between the sentences.

[Tables 9, 10, & 11 about here]

**Question response time.** Analysis of question response time with ‘and’ text (Table 12) showed that in Step 1, reading ability was a significant predictor of performance \( (r = .29, r^2 = .09, \text{adj } r^2 = .07; F(1, 50) = 4.68, p < .05) \). In Step 2, the inclusion of science self-concept also produced a significant model \( (r^2 \text{ change} = .151, F \text{ change} (1, 48) = 9.49; r = .49, r^2 = .24, \text{adj } r^2 = .21; F(2, 50) = 7.49, p < .01) \), reading ability demonstrated a significant negative coefficient and science self-concept, a significant positive coefficient. This shows that good reading skills reduce the time taken by students to successfully answer the comprehension question when the text uses additive connections. Interestingly, higher science self-concept increases the time take by students to correctly answer the comprehension question.

Comprehension performance with ‘because’ text (Table 13) showed that Step 1 produced a significant model \( (r = .33, r^2 = .11, \text{adj } r^2 = .09; F(1, 50) = 6.01, p < .05) \). Step 2 also resulted in a significant model \( (r^2 \text{ change} = .188, F \text{ change} (1, 48) = 12.85; r = .55, r^2 = .29, \text{adj } r^2 = .27; F(2, 50) = 10.16, p < .001) \), with reading ability producing a significant negative coefficient, and science self-concept a significant positive coefficient. Therefore, as with additive text, stronger reading skills predicted shorter response times to correctly answering the comprehension question with text which contains causal connections and
higher science self-concepts increased the time to take to correctly answer the comprehension question.

Comprehension performance with ‘no connective’ text (Table 14) showed that Step 1 resulted in a significant model \((r = .37, r^2 = .14, \text{adj } r^2 = .12; F(1, 50) = 7.83, p < .01)\). In Step 2 the model was also statistically significant \((r^2 \text{ change } = .09, F \text{ change } (1, 48) = 5.65; r = .48, r^2 = .23, \text{adj } r^2 = .19; F(2, 50) = 7.11, p < .01)\), again, reading ability was a significant negative coefficient and science self-concept a significant positive coefficient. These results mirror those found with the additive and causal connective texts.

[Tables 12, 13, & 14 about here]

**Summary**

Comprehension performance (accuracy and question response time) was not significantly modulated by the use of causal, additive and no connectives in the science text. However, female students were more accurate at responding to the comprehension question in comparison to males when the text contained a causal connection. Students’ demonstrated faster reading times after reading a causal connective compared to an additive and no connective. The regression models indicated that an increased reading ability predicts reduced response time to correctly answering comprehension questions with science text containing additive, causal and no connectives. Increased science self-concept slows response times to correctly answering comprehension questions.

**General Discussion**

The results suggest that achieving referential text cohesion is an important skill for secondary school students in determining comprehension of science text; when text is structured so that it is harder to connect sentences (by using synonyms) comprehension is
impaired. High cohesion text benefited students’ reading comprehension by shortening the
time taken to correctly answer comprehension questions after reading noun-repetition text.
Offline measures of comprehension showed that students achieved greater correct
performance after reading noun-repetition text, compared to text which used synonyms. In
comparison, connective text cohesion had less influence on students’ science comprehension.
Although a causal connective produced faster end of sentence reading times than additive and
no connective designs, no effect on comprehension performance (in terms of accuracy and
response time to correctly answering the question) was observed. Across both studies,
reading ability emerged as a unique predictor of reading performance for comprehension
accuracy and comprehension response times. Science self-concept also produced a significant
regression coefficient, but unlike reading ability these effects were not so clear across both
the studies. We first discuss the effects of text cohesion before considering the influence of
individual differences and the implications for educational practice.

Text Cohesion

To date, this is the first study to examine the effects of text cohesion devices in
isolation (referential devices and connective devices) in relation to secondary school
students’ reading of science text. Previous studies using a similar age group have modulated a
range of cohesive devices (e.g. avoiding pronouns, elaborating on concepts, use of
connectives, conceptual overlap) and have shown that text cohesion does not significantly
improve students comprehension of science text, only narrative text (Best et al., 2006;
McNamara et al., 2011). We highlight the importance of considering cohesive devices in
isolation when examining science text reading and further advocate that referential cohesion
and causal connectives are important areas to consider in school children’s science reading
(see McNamara et al., 2010)
Secondary school students’ comprehension of science text was facilitated by reading a noun-repetition text design (high cohesion) compared to one that used synonyms (low cohesion). Students were faster and more accurate at responding to comprehension question when they had read text that replicated the noun-phrase throughout the text. This suggests that noun-repetition promotes rapid integration of information to form a mental representation of the text (Zwaan & Radvansky, 1998) and avoids time-costly inference making (Best et al., 2005; Perfetti, 1994). No reading times effects were observed, however. This suggests that the students read the sentences without creating referential links as they went along (e.g. Noordman, Vonk, & Kempff, 2002), only when the comprehension question was asked did the student link the referents in the sentences (as evidenced by faster response times to the comprehension question after reading noun-repetition text). A significant implication for science teaching here is that it is possible for students to read texts with the goal of achieving low levels of comprehension. In order to promote higher levels of comprehension by connecting referents it is necessary for students to directly assess their understanding of the text (see, Andrade & Valtcheva, 2009; Singer, Harkness & Stewart, 1997). It is also important to note, that high cohesion (noun-repetition) text did not impair comprehension processes. It has previously been suggested that when readers do not need to make effortful links to comprehend the text (such as in the synonym design) they only achieve low levels of comprehension (McNamara et al., 1996). In this case, with young secondary school students, it seems that effortful processing should be encourage by regular use of comprehension, or ‘stop and think’ questions, rather than using a low cohesion (synonym) text design.

Causal connectives (i.e., 'because') facilitated students’ reading times of end of clause sentences. No benefits were observed from reading ‘and’ sentences or ‘no connective’ sentences. This is the first report to suggest that appropriate causal connectives can increase
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young secondary school students reading speed of science text. Broadly speaking these results are consistent with those reported with younger, 8-10 year old children reading narrative text by Cain and Nash (2011), in that the presence of an appropriate connective facilitated end of clause reading times. The indication, therefore is that even quite young children are sensitive to the influence of connectives, both when reading narrative text (Crain & Nash, 2011) and when reading expository science text, as in the present experiment.

The effects of reading times that we report also are consistent with the ‘specific inference hypothesis’; whereas ‘because’ has an explicit functional meaning (i.e., causal) in connecting text (i.e., A caused B to happen) ‘and’ could link the text by numerous possible relations (Millis et al., 1995). ‘Because’ is thought to enhance inter-clause integration by reactivating the first clause and by indicating to the reader how the second clause should be interpreted (connective-resource saving hypothesis). This reduces reading time to end of clause sentences (Millis & Just, 1994). These findings are comparable to those reported by Mak and Sanders (2013), who showed that when readers expected a causal relationship (as in the ‘because’ condition) reading processes are facilitated. Question accuracy and response time to correct answer was comparable across all three connective conditions. This suggests that causal connectives enhance on-line comprehension processes greater than offline. It has been previously suggested that students do not always understand the functional role of text connectives (e.g., Cain, Patson, & Andrews, 2005; Crosson, Lesaux, & Martinello, 2008), and this may hold true in this study. While the presence of ‘because’ seems to enhance on-line integration of the text it may not necessarily lead to enhanced inferential processing (i.e. the small leaves on a cactus plants causes the plant not to lose too much water), as reflected by the comprehension scores. Further investigations are needed to compare students who did and did not receive a tutorial informing the functional nature of connectives, prior to the reading task.
Individual differences in Science Text Comprehension

Reading ability was a key predictor throughout all regression models, with the exception of comprehension accuracy when reading a ‘because’ design text. Higher reading ability predicted better comprehension of noun-repetition text, synonym text and text connected with ‘and’ and ‘no connective’ text. With all text designs, reading ability predicted faster response times to correctly answering the comprehension question. This highlights the importance of general reading skills in determining comprehension (McNamara, 2009). This is consistent with the simple view of reading (Gough et al., 1996), that reading comprehension is the product of word decoding skills and that word decoding and vocabulary are strong predictors of reading comprehension across school grades (Schatshneider, Harrell, & Buck, 2007).

Previous research has shown that skilled readers make more frequent inferences to maintain text coherence (van den Broek, 1994); if this was the case we may expect to find that reading ability was a stronger predictor for performance low cohesion compared to high cohesion text. However, this study shows that, in general, reading ability predicted reading performance (comprehension and question response time) for high cohesion text, which demands fewer inferential processes, suggesting that reading skills are a more significant determiner than inferential skills for successful comprehension of science text. Nevertheless, the current data shows support for the idea that reading skills are less important when the text design is more cohesive, and the readers do not have to infer a causal relationship as determined by the use of a ‘because’ connective. This is in contrast with Ozuru et al. (2009), who reported that students with a high reading ability gained maximum benefit from high cohesion. However, Ozuru et al. (2009) based their conclusion on college-aged students, with a large age range of 18-37 years.
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Science self-concept also predicted reading comprehension, but only with synonym text. This goes some way to support the role of academic self-concept in determining achievement (Marsh & Martin, 2011). Considering that science self-concept only predicted comprehension with the more difficult, low cohesion, text design it seems likely that increased self-perception enhances cognitive factors which are necessary for successful comprehension, such as task engagement, persistence and the use of metacognitive (e.g. inference making) strategies (Pintrich, 1999; Wigfield, 1994). Somewhat surprisingly, science self-concept increased the time taken by the students to correctly answer the inference question for all the connective text structures (because, and, no connective). It is well established that there is a strong relationship between academic self-concept and academic achievement in students (Ackerman, 2003; Marsh, 2007; Yara, 2010). However, the causal relationship between the two is controversial (e.g., Guay, Marsh, & Boivin, 2003; Marsh & Martin, 2011), with mounting evidence suggesting that academic self-concept both affects and is affected by academic achievement (e.g., Marsh, 1990a,b, 2007; Marsh & Craven, 2006). As such, any causal relationship between self-concept and reading times in the present experiment may be more complex. Nonetheless, we consider two possible explanations. Firstly, those with a higher science self-concept are more competent in their self-perception because they take time to consider their responses to question, which leads to greater accuracy. Secondly, those students with a lower science self-concept have low confidence in their abilities; hence increased anxiety leads them to rush to answer the question. These explanations need not be mutually exclusive; instead both processes may be at work. Further investigations to examine the response strategy adopted by students are needed to substantiate these suggestions. No effects of self-esteem emerged; indicating that specific self-perception of science self-concept is a more useful predictor of attainment in science (Byrne, 2002).
Educational implications

Given that achieving a coherent text representation is the hallmark of sound comprehension it is crucial that educational policies focus on the skill of achieving text cohesion to improve science comprehension, and therefore attainment. As evidenced in this study, one way in which this could be implemented into science teaching is to produce textual information which is high cohesion. The importance of ‘learning away from the teacher’ is becoming an increasing issue in many educational reports (e.g., Ofsted, 2012). Providing students with stimulating, well structured (high cohesion) text may provide the start of effective independent learning. In contrast with measures of text complexity such as the Flesch-Kincaid grade level or the Dale-Chall readability formula which use sentence length as a proxy for text difficulty, we suggest that providing the reader with short sentences may not be beneficial. Instead, longer sentences linked a by an appropriate connective may lead to a greater understanding of the text. It is important to note that increasing sentence complexity by the use of connective devices may only be beneficial when using a causal connective (‘because’) to depict a causal event (Cain & Nash, 2011). In terms of number of referential expressions used, reducing text complexity by using noun-repetition is likely to benefit students’ comprehension of science text. While reading high cohesion text is likely to scaffold a child’s learning from science text, it is also important that students are taught how to achieve text cohesion. Policies which teach students about the functional nature of connectives and the use of common synonyms in science language may prove especially beneficial.

The over-riding importance of reading ability, compared to other individual variables (science self-concept and self-esteem) has implications for the education of science in secondary schools. Strategies to improve students’ core reading skills (e.g. vocabulary and reading fluency) have the potential to lead to significant increases in science achievements
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(for examples see McNamara & Kendeou, 2011). Studies suggest that it is most effective to target early school years, prior to when fluent reading develops (Kendeou, van den Broek, White, & Lynch, 2007). Additionally, at later stages of education reading strategies which focus on scientific reading skills are likely to enhance science attainment (Akhondi, Malayeri, & Samad, 2011).

Conclusion

Students’ comprehension processes (accuracy and question response time times) were facilitated by text designs that used noun-repetition (i.e., higher in referential cohesion). Students’ demonstrated faster reading times when reading sentences that followed a causal connective (‘because’). However, this did not produce a clear benefit to comprehension accuracy. Reading ability predicted better comprehension of noun-repetition and synonym text designs and faster correct responses to comprehension questions. In addition, reading ability predicted better comprehension for both unconnected texts and texts that included additive (‘and’) and causal (‘because’) connectives, and quicker corrected responses in the connected text conditions. Finally, higher science self-concept was associated with slower correct response times for comprehension questions. The study provides a first insight into the potential importance of teaching text cohesion and improving core reading skills to promote attainment in secondary education of science.

Acknowledgements

This research was financially supported by The Leverhulme Trust. Project title (removed for review).
References


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THE IMPORTANCE OF SCIENCE TEXT COHESION

Daneman, M., & Hannon, B. (2001) Using working memory theory to investigate the construct validity of multiple-choice reading comprehension tests such as the SAT. *Journal of Experimental Psychology: General, 130*, 208-223


THE IMPORTANCE OF SCIENCE TEXT COHESION


THE IMPORTANCE OF SCIENCE TEXT COHESION


THE IMPORTANCE OF SCIENCE TEXT COHESION


THE IMPORTANCE OF SCIENCE TEXT COHESION


O’Reilly, T., & McNamara, D. S. (2007). Reversing the Reverse Cohesion Effect: Good Texts can be better for strategic, high knowledge readers. *Discourse Processes, 43*, 121-152. doi: 10.1080/01638530709336895


http://www.ofsted.gov.uk/resources/moving-english-forward


http://dx.doi.org/10.1016/j.learninstruc.2008.04.003
THE IMPORTANCE OF SCIENCE TEXT COHESION


http://dx.doi.org/10.1016/S0883-0355(99)00015-4


doi:10.1111/1467-6494.694157


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