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# The impact of text coherence on learning by self-explanation

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**Abstract**

Previous research has shown that encouraging learners to explain material to themselves as they study can increase their understanding. Furthermore, different types of material (e.g. text or diagrams) influence learners' self-explanation behaviour. This study explores whether the coherence of text impacts upon the self-explanation effect. Forty-eight low-knowledge learners (university students) learnt about the circulatory system with text that was designed to be either maximally or minimally coherent. Half of these learners also received self-explanation training. Results showed that learners given maximally coherent text learnt more, as did learners who self-explained. However, this was not because coherent text increased self-explaining. Instead minimally coherent text significantly increased the number of self-explanations that learners made. It is suggested that self-explaining in the minimal text condition served to compensate for weaknesses and gaps in the text, whereas self-explaining in the maximal text condition may have led learners to detect flaws in their mental models and repair them. Consequently, rather than providing a minimally coherent text which compels low knowledge learners to self-explain to overcome its deficits, we should instead encourage learners to self-explain from well structured and explicit text.


*Keywords:* Text comprehension; Self-explanation; Strategy

## 1. Introduction

Not all learning from text is successful. In fact, a body of research in a variety of areas has shown that in order for learners to elicit the highest gains from studying, they should actively construct their understanding as they read. This active processing of text may be encouraged by a variety of strategies – for example, students could take notes, draw diagrams of what they read, answer questions posed by others or generated by themselves. One strategy that has been studied extensively in recent years is that of self-explaining. A self-explanation is knowledge generated by learners that states something beyond the information they are given. Extensive research has shown that students develop a deeper understanding of material they read if they self-explain. Texts themselves can be written in ways that either promote or inhibit active processing. A number of studies reviewed below have found that texts on the same topic manipulated in seemingly subtle ways can have dramatic impacts upon learning. The current study was designed to explore the relationship between the self-explanation strategy and the specific features of the text, and how this impacted on both what and how students learnt.

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### *1.1. The impact of self-explaining on learning*

Much research has acknowledged that active construction of understanding during learning is important. One learning strategy that encourages learners to do this is self-explanation. A self-explanation (shorthand for self-explanation inference) is additional knowledge generated by learners that states something beyond the information they are given to study. For example, in the material used in this study, we might tell learners "*The heart is the muscular organ that pumps blood through the body*", and would code a self-explanation if the learner responded "*so it's got to be a muscle that is strong enough to pump blood around the whole body*".

A substantial number of studies have reported that students develop a deeper understanding of material they have studied if they generate explanations to themselves whilst learning (Aleven & Koedinger, 2002; Bielaczyc, Pirolli, & Brown, 1995; Chi, Bassok, Lewis, Reimann, & Glaser, 1989; Chi, deLeeuw, Chiu, & Lavancher, 1994; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001; Cote, Goldman, & Saul, 1998; Renkl, 1997, 2002; Wolfe & Goldman, 2005). In the original study, Chi et al. (1989) gave college students learning mechanics three problem examples containing text and diagrams to study. Students' performance on end of chapter exercises and isomorphic problems were then measured. They found students who spontaneously generated a large number of self-explanations (SEs) during learning scored over twice as highly on the post-test as those who gave few explanations. High SE students also demonstrated better monitoring of their own understanding whilst learning. In a follow-up study, Chi et al. (1994) asked high school students to read a biology text. Half were prompted to self-explain and half read the text twice. The group that self-explained learned significantly more (26%) than the reading only group (16%). Subsequently, a number of studies have confirmed this effect and examined the scope of its application.

It is evident that these effects are observed in a wide variety of domains (e.g. physics problem solving (Chi et al., 1989; Conati & VanLehn, 2000) probability (Renkl, 1997); cardio-vascular system (Chi et al., 1994, 2001), geometry (Aleven & Koedinger, 2002), history (Wolfe & Goldman, 2005), and Lisp programming (Bielaczyc et al., 1995)). Therefore, we know the beneficial effects of self-explanations can be found for both procedural and conceptual domains, can promote analogical transfer (Neuman & Schwarz, 1998) and are not limited to learning from examples.

The benefits of self-explaining are not only present when students spontaneously generate explanations. Students who are prompted to give self-explanations also profit from this strategy (Chi et al., 1994). Nor are the results due to the fact that students who know more to begin with self-explain more. Studies such as Chi et al. (1994) and Ainsworth and Loizou (2003) have found no relationship between the degree of self-explaining and prior knowledge. Although studying whilst self-explaining takes longer than studying without self-explanation, the results are not simply due to time on task. Renkl (1997) required learners to study worked out examples of probability problems for 25 min. Those learners who self-explained more (especially those who anticipated solution steps or referred to principles) learnt more, even when time was controlled.

A number of studies have compared self-explaining to other learning strategies, the simplest being to reread the material (as in Chi et al., 1994). As measuring self-explanation often requires learners to speak out loud, studies have contrasted self-explanation to simple prompts to speak out loud. Walthen (1997, quoted in Chi, 2000) found that self-explanation was a more effective strategy than giving standard verbal protocols as did McNamara (2004) who compared self-explanation to reading out loud. O'Reilly, Symons, and MacLatchy-Gaudet (1998) compared the performance of three groups learning about the cardio-vascular system – one who repeated sentences out loud, one who engaged in elaborative interrogation (answering questions such as "why does it make sense that …") and one who were given typical self-explanation prompts. The self-explanation group had significantly better cued recall and recognition than either of the other two groups.

Self-explanation can help learners actively construct understanding in two ways; it can help learners generate appropriate inferences and it can support their knowledge revision (Chi, 2000). If a text is in someway incomplete (and most are – see below) then learners generate inferences to compensate for the inadequacy of the text and to fill gaps in the mental models they are generating. Readers can fill gaps by integrating information across sentences, by relating new knowledge to prior knowledge or by focusing on the meaning of words. Self-explaining can also help in the process of knowledge revision by providing a mechanism by which learners can compare their imperfect mental models to those being presented in the text. They are then in a position to detect conflicts between their beliefs and the appropriate ones, and so begin to revise their mental model.

Whilst no one would argue that self-explanation is the only knowledge building strategy, this evidence suggests that it is an effective one and a strategy worth encouraging students to utilise. Consequently, studies have examined if learners can be taught to self-explain. Bielaczyc et al. (1995) established that students who were trained to self-explain, were subsequently able to apply the strategy and showed significant increases in performance compared to untrained students. Renkl, Stark, Gruber, and Mandl (1998) found that self-explanation training could improve participants' performance on near and far transfer items. McNamara (2004) asked learners to read four texts and whilst doing so trained them in a reading strategy called Self-Explanation Reading Training, which involves comprehension monitoring, paraphrasing, making bridging inferences, elaborating ideas, using logic and making predictions. During the training period, text comprehension was enhanced (compared to students who read out loud) and after training this improvement was maintained on a new text (but only for low knowledge students). Finally, researchers have also found that computer coaches can be successful at helping students to self-explain (Aleven & Koedinger, 2002; Conati & VanLehn, 2000; McNamara, Levinstein, & Boonthum, 2004).

#### *1.1.1. Does the form and content of material influence the self-explanation effect?*

Recently studies have begun to address the question of how material should be designed to support self-explaining. Of most relevance to this paper are the uses of instructional explanations and of diagrams. Renkl (2002) supplemented self-explanation training with material that included instructional explanations (available on demand). He found participants who were provided with instructional explanations learnt more and that they performed especially well on far transfer items. This effect was independent of prior knowledge. However, Chi et al. (2001) compared students' performance when their tutors could either provide instructional explanations (and feedback) or were inhibited from so doing and could only prompt students to think about the material more deeply. Students who were prompted learnt just as well as those who heard more explanations. At one level, these studies look inconsistent. However, it should be remembered that Renkl used on-demand instructional explanations whereas Chi et al.'s tutors were providing explanations to learners when the tutors, not the students, deemed them appropriate.

Ainsworth and Loizou (2003) compared students learning about the structure and functioning of the cardio-vascular system with either diagrams or text. They found that diagrams increased both the quality and quantity of learners' self-explanations. Furthermore, learners' performance in the diagrams condition was more heavily dependent on their use of self-explanations. They proposed that the explanation for the way that diagrams influenced the application and effectiveness of the self-explanation strategy was due to the multiple cognitive, semantic and affective differences between the types of representation. In particular, they suggested that the diagrammatic representations enhanced self-explaining by supporting computational offloading and by making information more explicit.

Consequently, in this study we wanted to explore if text could be written in such a way to make self-explaining more effective. In particular, we have focused on textual coherence as this has clear analogies to the work on instructional explanations and on learning with diagrams.

### *1.2. The impact of text coherence on learning*

When learners are coming to understand complex and unfamiliar material, it seems reasonable to assume that the way this material is written will impact upon their understanding. One factor, that has received a considerable amount of attention recently, is the coherence (or cohesion) of the text. Text coherence can be defined to be the extent to which the relationships between the ideas in the text are made explicit (e.g. McNamara, 2001). It is normally achieved by manipulating cohesive text elements in ways that indicate these relations. For example, consider this quote from a text about the structure and function of the cardio-vascular system

> "*In the lungs, carbon dioxide leaves the circulating blood and oxygen enters it. The oxygenated blood returns to the left atrium. It is pumped through the bicuspid valve into the left ventricle*."

with another more coherent version

> "*In the lungs, carbon dioxide that has been collected from cells as blood has passed around the body, leaves the circulating blood and oxygen enters it. This means that the blood is now oxygenated. This oxygenated blood returns to the heart. However, this time the blood enters the left atrium. This oxygenated blood is then pumped through the bicuspid valve (the a-v valve on the left side of the heart) from the atrium into the left ventricle*."

The second text is noticeably longer because it has provided elaborations that the learner needs to help them make sense of the information (e.g. "*that the bicuspid valve is the a-v valve on the left side of the heart*"), it has replaced pronouns with nouns making text more explicit (e.g. "*it*" to "*this oxygenated blood*"), and shown connections between ideas (e.g. *This means that*). These are all changes that increase the local coherence of the text (i.e. the coherence of individual sentences and transitions between them). Global coherence refers to the macrostructure of the text, for example, by the use of headings and by linking paragraphs to the overall topic. For example, the text above could be made more globally coherent by addition of a title (e.g. "Blood Flow in the Heart and Lungs").

A number of studies have considered whether changing the text in these ways can aid learning. Britton and Gulgoz (1991) asked participants to read a passage of text regarding the air war in Vietnam. They found that although participants could recall the content of the text, their understanding of it was fairly limited. The researchers then revised the text at all points where they considered that local text coherence had broken down. For example, they added synonymous terms and connective ties, and provided background information that was not made explicit in the text. They found that students who read the revised version of the text had better recall of the material and their representation of the material was more like an expert, without fundamental misconceptions.

Vidal-Abarca, Martinez, and Gilabert (2000) rewrote history texts to make clearer the causal explanatory links between concepts, which helped learners to generate a deeper understanding of the text. They suggest the most important text manipulation performed by Britton and Gulgoz was to improve causal explanations.

The positive impact of coherent text has been replicated using a variety of topics, including social studies (McKeown, Beck, Sinatra, & Loxterman, 1992) and the life of mammals (McNamara, Kintsch, Butler Songer, & Kintsch, 1996). But, research has shown that the advantages of text coherence are not uniform, they depend upon the characteristics of learners, the difficulty of text and the way that learning is measured. One important characteristic is the readers' prior knowledge. For example, in McNamara et al.'s (1996) study, students were categorized as either high or low knowledge readers, according to pre-test question scores, regarding the topic area (heart disease) that was to be studied. During the experiment participants read one of four passages of text. These were alike in their content but differed in their level of local and/or global coherence. Post-test questions ranged from simple retrieval questions that could be answered by directly referring to information in the text, to more complex questions that required wider knowledge or application of the material to a novel situation. In these conditions it was found that whilst low knowledge readers benefited from text that was coherent at both the local and global level, high knowledge readers benefited from a minimally coherent text for more complex questions. Similarly, McNamara and Kintsch (1996) found that less coherent text was more helpful for high-knowledge learners when they were asked questions which revealed their understanding of the material (for example, keyword sorting problem or open ended questions asked after a delay).

McNamara and Kintsch (1996) suggest that the explanation for the effect lies in the degree of active processing required in order to understand the text. Whilst high knowledge readers are capable of active processing even when the text is easy to understand, they are less likely to do so with material that does not pose a challenge. Thus, a text that lacks coherence results in greater post-test scores by forcing the high knowledge reader to work harder for a deeper level of understanding, leading to better comprehension. McNamara (2001) tested this explanation by providing readers with both low and high coherent texts, but in different orders and combinations. She found that high knowledge readers benefited from reading low coherent text first, whereas the reverse was true for low knowledge readers. Low coherence text also resulted in greater reading times (per word) than text that had higher coherence. McNamara argues that this confirms that beneficial effects of low coherence texts on high knowledge learners are to do with active knowledge-based processing during reading, rather than at time of testing.

The second factor that has been shown to interact with text coherence is the way that learning is measured. Kintsch (1998) distinguishes between two levels of understanding: the textbase and situation model. The textbase is knowledge of elements and relations that are directly derived from the text itself. In contrast, the situation model, whilst partly based on the textbase, also includes knowledge added on the basis of general knowledge, personal experience, knowledge of language, etc. Consequently, the situation model is integrated into one's ongoing memory for knowledge and experience. The more explicit and coherent the original textbase, the less need there is for a learner's prior knowledge in creating the situation model.

In many of the studies discussed above, researchers have designed outcome measures that distinguish between questions that could be answered on the basis of the textbase alone versus those that also require the situation model. Typically, measures such as recognition tests, explicit multiple choice tests and straight recall are considered measures of the textbase, whereas questions that require inferences not provided by the text (e.g. open ended questions, tests of mental model understanding) are considered measures of the situation model. However, it should be acknowledged that this is on a continuum. In some cases, measures like recall may also include elaborations and inferences not found in the textbase.

In the studies of McNamara and Kintsch (1996) and McNamara et al.'s (1996) the benefits of low coherence (for higher knowledge learners) were primarily found on measures that relied more on the situation model (i.e. sorting tasks, inferential questions), whereas measures that rely on the textbase (i.e. recall, multiple choice) were better with highly coherent text, irrespective of prior knowledge. However, McNamara (2001) found that the low coherence advantage for high knowledge learners' manifested at the textbase and not situation model level. Gilabert, Martinez, and Vidal-Abarca (2005) found that simple recall measures were facilitated by a text that decreased inferential activities, but that inference questions were helped by a text that increased inferential activities.

These studies make it clear that the important factor is not the design of the text per se, but active processing of texts by learners, especially if the purpose is for learners to generate a deeper understanding of the material. The common feature that distinguishes successful from unsuccessful learning from text is active rather than passive text processing, but this active processing may need to be supported in different ways for different learners.

## 2. Present study: the effect of self-explaining and text coherence when learning from text

The current study aims to explore the roles of self-explanation and text coherence for novices learning relatively complex material. The original passage of text for this study is taken from the passage used by Chi et al. (2001) on the circulatory system. The design adopted is similar to that of Chi et al.'s (1994) study. However, the original text was adapted following the procedure of McNamara et al. (1996) to form two passages of text, identical in their content but differing in their coherence at both the local and global level. Four experimental conditions resulted which allowed a comparison to be made between the effects of self-explanation and text coherence on learning. We expected to confirm the well-established findings that students learn more when they self-explain and that novices benefit from coherent text. However, the main focus of the research concerns the relationship between text coherence and self-explaining and two key questions are considered.

1. Does the level of coherence influence the number of self-explanations generated?
   We predicted that the minimally coherent text would increase the number of self-explanations. We propose that this is because (a) learners in the minimal condition will produce explanations that are given in the text in the maximal conditions and (b) because learners will need to actively process the text to make sense of it due to its many limitations and gaps.
2. Is maximally or minimally coherent text more beneficial to learning when accompanied by self-explanations? Two alternative hypotheses are proposed:

(a) The minimal text condition when accompanied by self-explanation training will present the optimal conditions for learning. Minimal text is hypothesized to increase self-explaining, and self-explanation is known to improve learning. Consequently, low knowledge learners who self-explain will not only be able to overcome the limitations of less coherence but will actively benefit from it as they will have a greater chance to engage in an effective learning strategy.

(b) Maximally coherence text accompanied by self-explanation will present the optimal condition for learning. Although maximal text is hypothesized to result in less self-explanation than minimal text, when learners do self-explain they will achieve the benefits of both text coherence and self-explanation.

## 3. Method

### 3.1. Design

The experiment had a three-factor mixed design. The first factor, coherence, was a between groups measure with two levels; whether the participant studied minimal or maximal coherent text. The second factor, self-explanation, was a between groups measure with two levels; whether participants used a self-explanation strategy whilst reading the text, or whether they read in silence. The third factor, time (pre-test and post-test), was a within groups measure. This design resulted in four experimental groups with 12 participants in each condition. Participants were randomly assigned to conditions, although we ensured that the male/female ratio did not differ across the conditions.

### *3.2. Participants*

Participants were 48 University of Nottingham undergraduate volunteers (25 female and 23 male) who ranged in age from 20 to 24 years. No participant had studied subjects with a major biological component (such as medicine, genetics, and biology) past the age of 16.

### *3.3. Materials*

#### *3.3.1. Text*

The texts in the current study were adapted from those of Chi et al. (2001) and address the structure and functioning of the circulatory system. Each of the 86 sentences (a total of 1415 words) in the original passage was manipulated to form a passage of maximally coherent text and a passage of minimally coherent text (see Appendices 1 and 2).

**Maximally coherent text:** Each sentence in the original text was adapted following these rules (McNamara et al., 1996):

1. Replacing a pronoun with a noun when the referent was potentially ambiguous (e.g. replacing '*it*' with '*the valves*').
2. Adding descriptive elaborations to link unfamiliar concepts with familiar ones and to provide links with previous information presented in the text (e.g. replacing '*the ventricles contract*' with '*the ventricles (the lower chambers of the heart) contract*').
3. Adding connectives to specify the relation between sentences (e.g. *therefore, this is because, however, etc*).

Maximal coherence at a global level was achieved by adding topic headers that summarised the content of the text that followed (e.g. '*The flow of the blood to the body: arteries, arterioles and capillaries*') as well as by adding macropropositions which linked each paragraph to the overall topic (e.g. '*a similar process occurs from the ventricles to the vessels that carry blood away from the heart*'). Table 1 shows the numbers of text adaptations that were made.

The text that resulted from this process was considerably longer than the original at 3496 words including 15 headings and 145 sentences.

**Minimally coherent text:** These local and global text manipulations were reversed for the minimal coherence text (e.g. noun phrases were replaced with pronouns, connectives were removed and headers were not included). The minimal text consists of 1075 words in 119 sentences.

Overall, the concepts and information available in the two manipulated texts remained identical both to the original passage and to each other, although this was not the case at the level of the individual sentence. Table 2 shows an example from the original text. In the minimal text, a pronoun has replaced the noun phrase and so participants must understand the anaphoric reference to the previous sentence '*the oxygenated blood returns to the left atrium*'. Alternatively, in the maximal text the bicuspid valve is redefined, although this information was previously given above.

Table 1
Text adaptations in the maximal text

| Local | | | Global | |
|---|---|---|---|---|
| Pronouns | Elaborations | Connectives | Headings | Macropropositions |
| 30 | 120 | 78 | 15 | 14 |

Table 2
An original sentence with a minimal and maximal variant

| Original | Minimal | Maximal |
|---|---|---|
| The oxygenated blood is then pumped through the bicuspid valve into the left ventricle | It is pumped through the bicuspid valve into the left ventricle | This oxygenated blood is then pumped through the bicuspid valve (the a-v valve on the left side of the heart) from the atria to the left ventricle |

The current study was partly concerned with the influence of expository text manipulation on sentence comprehension, thus it was felt important that the to-be-learned material continued to resemble that of a common text. In order to achieve this, a departure was made from Chi et al.'s (1989, 1994) studies in which sentences were presented separately on their own page. In the current study, the sentences were presented following each other as part of a continuous passage. Each sentence of the text was presented on a separate line. In the minimal coherence condition, sentences were presented in one continuous block of text, thereby reducing the macro coherence. In the maximal coherence condition, sentences were still presented on separate lines. However, they were assembled into paragraphs of related material and separated by headings.

### *3.3.2. Pre-test and post-test questions*

The pre-test and post-test questions were a subset of those used by Chi et al. (2001). These questions were designed to assess different types of knowledge ranging from those that could be answered fairly directly from the textbase (multiple choice and definition questions) to those that required inferences to be made and so also depended upon the situation model (implicit questions and knowledge inference questions). The total numbers of questions were reduced due to shorter duration of this experiment compared to Chi et al. (2001). Total marks available for each answer were shown in brackets after each question as an indicator of the level of detail required.

**Blood path diagram:** Subjects were asked to draw the blood path on the outline of a human body at pre-test and post-test. They were encouraged to use labels and a key if they desired. The maximum total number of marks available was 10.

**Definitions:** Ten terms were provided at pre-test and post-test and participants were asked to define them. The maximum total number of marks available was 24.

**Explicit questions:** Twelve questions took the form of multiple-choice questions where participants had to circle the correct answer from four possible answers. These were answered at both pre-test and post-test. The maximum total number of marks available was 12. These questions were designed to be answered from the textbase alone.

**Implicit questions:** Six questions required the participant to integrate information from two or more lines of the text, or from non-consecutive paragraphs. For example, the answer to question 1: '*Why do we have valves in veins, but not in arteries or capillaries?*' was not explicitly stated in either the maximum or minimum coherence text. Students were required to integrate information from a series of sentences in the text relating to the structural differences between three types of vessels and the relation to the function of these vessels in order to answer this question. These questions were likely to test the situation model formed by the participants rather than factual recall of the textbase. The maximum total number of marks available was 18.

**Knowledge inference questions:** Six questions required the generation of new knowledge by inferring information from the text. Answering these questions required a good deal of understanding and the use of prior knowledge (and hence proved useful in measuring the mental model formed by the participant). For example, question 2, '*what are the consequences at a cellular level of having a hole in the septum?*', required the student to infer the role of the septum from information presented in the texts, because it was not explicitly mentioned in either the minimal or maximal coherence texts. Again, these questions tested the participants' situation model rather than the textbase. The maximum total number of marks available was 18.

## *3.4. Procedure*

Students were tested individually in a quiet room. At each stage in the experiment, participants were asked if they understood the instructions, and any outstanding questions were dealt with. Debriefing followed completion of the study.

The experiment consisted of three basic stages:

**Pre-tests:** Participants were given an outline of the human body and instructed to 'draw the blood path to all parts of the body'. Participants then answered the 10 definitions followed by 12 multiple-choice questions.

**Study phase:** For those in the self-explanation condition, a training session was conducted prior to the study phase (see below). Participants in the self-explanation condition were instructed to self-explain after every sentence they read. These were tape recorded, and the experimenter did not sit in earshot to minimise any inhibition participants may have felt in the presence of the experimenter, as well as to emphasise that the learning strategy was for their own benefit. All students were informed that they were to be presented with a passage of text containing information about the heart and encouraged to read carefully as following study they would be receiving a series of questions relating to information presented in the passage. Participants in the non self-explanation condition were required to read the passage of text twice in order to reduce variability in the time spent reading between conditions.

**Post-test:** Immediately after studying the material, participants answered all the post-test questions. These consisted of the pre-test questions, as well as an additional set of implicit and knowledge inference questions.

**Self-explanation training:** This was an adapted version of that given by Bielaczyc et al. (1995). A training booklet was created that informed participants of the benefits of self-explanation, including the importance of identifying and elaborating the main ideas in the text, linking ideas with previous information or examples, as well as integrating the material with any prior knowledge they may have had. To demonstrate the self-explanation strategy, three written examples were developed of possible self-explanations that might be generated whilst someone was reading passages taken from a biology textbook. Following this, participants were required to read an extract taken from Chi et al.'s (1989) physics study. Examples of participants' responses from this study were then used to demonstrate the differences between paraphrasing, monitoring and self-explanation. This short training scheme was developed so that an experimenter was not required to prompt the learner to self-explain (as in Chi et al., 1989 or Ainsworth & Loizou, 2003) to remove potential experimenter bias. It is not, however, comparable to long term self-explanation training (e.g. McNamara, 2004), whose intention is to create more lasting changes in learners' strategies.

### *3.5. Coding of verbal protocols*

The self-explanations made by participants were transcribed and coded according to a scheme based on Renkl (1997) and then modified by Ainsworth and Loizou (2003). The only significant differences are that the category of anticipative reasoning was not felt appropriate and hence removed, whilst false self-explanation was added as Wilkin (1997) found the format of material influenced the accuracy of self-explanations.

**Principle-based explanation:** This category was scored if participants made reference to the underlying domain principles in an elaborated way (e.g. "*this is due to diffusion as molecules are spreading from a greater concentration to a lesser concentration*."). In this domain, it was only scored with respect to diffusion.

**Goal-driven explanation:** Self-explanations were coded as goal-driven if the participant made an explanation that inferred a goal to a particular structure or action. For example the utterance '*valves come together to prevent blood flowing in the wrong direction*' would be coded as a goal-driven explanation because the learner is inferring that the role of the valves is to prevent back-flow of blood.

**Elaborative explanation:** This category was scored if the participant inferred information from the sentence in an elaborated manner. Metaphors or analogies were coded in this category as well as elaborations that linked previous ideas presented in the text. The utterance '*so the skeletal muscles in the blood vessels squeeze the blood in the right direction, a bit like a hand squeezing toothpaste out a tube*' would be placed in this category.

**Noticing coherence:** If participants noticed an association between a previous concept and the current material, it was coded in this category.

**Monitoring-negative/positive:** Statements indicating that a student did not understand/understood the material.

**Paraphrase:** An utterance was coded as such if the participants were merely reiterating the information presented in the text in their own words such that no new information was added to the material in the form of an explanation. This information could come from more than one sentence in the original text.

**False self-explanation:** An utterance was so scored if the participant made a self-explanation according to one of the above categories, but the explanation they made was incorrect. For example, the utterance '*blood enters the left side of the heart, so it must leave by the right side of the heart*', was coded within this category as the participant is inferring the direction of blood flow through the heart, but the elaboration is faulty.

Table 3
Pre- and post-test scores on blood path diagrams, definition questions and multiple choice questions by self-explanation and text coherence

| | | Self-explainers | | | | Non-self-explainers | | | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Max ($n = 12$) | | Min ($n = 12$) | | Max ($n = 12$) | | Min ($n = 12$) | | $N = 48$ | |
| Blood path diagrams/10 | Pre-test | 0.75 | (0.97) | 1.42 | (1.17) | 0.67 | (0.97) | 1.33 | (1.44) | 1.04 | (1.20) |
| | Post-test | 4.25 | (2.14) | 4.29 | (1.74) | 3.17 | (1.99) | 2.50 | (1.51) | 3.55 | (1.95) |
| Definitions/24 | Pre-test | 4.83 | (1.71) | 4.29 | (1.86) | 4.71 | (2.42) | 6.00 | (3.03) | 4.96 | (2.33) |
| | Post-test | 12.92 | (2.67) | 11.38 | (4.41) | 9.96 | (3.60) | 9.50 | (2.26) | 10.94 | (3.50) |
| Multiple choice/12 | Pre-test | 6.63 | (2.19) | 6.50 | (1.68) | 6.63 | (2.17) | 5.71 | (2.45) | 6.50 | (1.94) |
| | Post-test | 10.00 | (1.71) | 9.75 | (1.91) | 9.67 | (1.62) | 10.30 | (1.50) | 9.94 | (1.66) |

## 4. Results

### 4.1. Learning outcomes

Learning was assessed using five different tests. Participants completed a blood path diagram, definition and multiple choice questions at pre- and post-test. Implicit questions and knowledge inference questions were answered at post-test only.

#### 4.1.1. Explicit questions

To examine the effect of condition on the students' learning, a mixed [2 by 2 by 2] MANOVA was conducted on the multiple choice, definition and blood-path diagram questions. The design of the analysis was self-explanation (self-explainers, non self-explainers), by coherence of material (maximal coherence, minimal coherence) with a repeated measure of time (pre-test, post-test) (Table 3).

Multivariate analysis revealed a main effect of time ($F(3,42) = 132.1$, $p < 0.001$) and an interaction between time and self-explanation condition ($F(3,42) = 4.64$, $p < 0.007$). Univariate analyses revealed a significant main effect of time on blood-path diagram scores ($F(1,44) = 87.72$, MSE = 1.72, $p < 0.0001$, $\eta_p^2 = 0.66$) and self-explanation condition ($F(1,44) = 4.4$, MSE = 3.15, $p = 0.042$, $\eta_p^2 = 0.09$) modified by a significant interaction between time and self-explanation condition ($F(1,44) = 6.38$, MSE = 1.72, $p < 0.001$, $\eta_p^2 = 0.13$). Simple main effects showed that the only significant difference between self-explanation conditions was at post-test ($F(1,44) = 10.49$, MSE = 2.43, $p < 0.001$) with participants in the self-explanation condition scoring significantly higher at post-test (mean = 4.27, SD = 1.91) than those in the non-self-explanation condition (mean = 2.83, SD = 1.76).

There was a significant main effect of time on definition question scores ($F(1,44) = 140.45$, MSE = 6.12, $p < 0.0001$, $\eta_p^2 = 0.76$), with participants in all conditions showing an increase in definition question scores at post-test. This was modified by a significant interaction between self-explanation condition and time ($F(1,44) = 10.11$, MSE = 6.12, $p < 0.005$, $\eta_p^2 = 0.19$). There were no difference between the conditions at pre-test but there were at post-test; with self-explainers scoring more (mean = 12.14, SD = 3.64) than non-self-explainers (mean 9.73, SD = 2.94) ($F(1,88) = 8.49$, MSE = 8.25, $p < 0.005$).

Finally, there was a single significant main effect of time on multiple choice question scores ($F(1,44) = 158.00$, MSE = 1.82, $p < 0.0001$, $\eta_p^2 = 0.78$), with participants in all conditions showing an increase in multiple choice question scores at post-test.

#### 4.1.2. Implicit and knowledge inference questions

Answers to the questions were marked against model answers by the second author and the first author remarked a random sample of 50% (inter-rater agreement, $r = 0.91$, $p < 0.001$) (see Table 4).

Table 4
Post-test scores on implicit and knowledge inference questions by self-explanation and text coherence

| | Self-explainers | | | | Non-self-explainers | | | |
|---|---|---|---|---|---|---|---|---|
| | Max ($n = 12$) | | Min ($n = 12$) | | Max ($n = 12$) | | Min ($n = 12$) | |
| Implicit/18 | 10.54 | (3.36) | 6.96 | (3.56) | 7.17 | (2.87) | 6.42 | (3.20) |
| Know. inf./18 | 9.50 | (2.88) | 7.04 | (2.80) | 4.58 | (2.82) | 4.38 | (1.40) |

Multivariate analysis revealed a main effect of self-explanation condition ($F(2,44) = 14.51$, $p < 0.001$) and a trend for a main effect of text coherence ($F(2,44) = 2.60$, $p < 0.08$). Analysis of the implicit post-test questions revealed a significant effect of self-explanation ($F(1,44) = 4.35$, MSE = 10.57, $p < 0.05$, $\eta_p^2 = 0.09$) with self-explanation leading to significantly higher scores (mean = 8.75, SD = 3.83) than those who did not self-explain (mean = 6.79, SD = 3.00). Text coherence also had a significant effect on implicit question scores ($F(1,44) = 5.33$, MSE = 10.57, $p < 0.026$, $\eta_p^2 = 0.11$), with scores in the maximum coherence condition (mean = 8.85, SD = 3.51) significantly higher than in the minimum text coherence condition (mean = 6.69, SD = 3.31). There was no interaction between coherence and self-explanation. For knowledge inference questions, there was a single significant effect − self-explainers scored significantly more (mean = 8.27, SD = 3.05) than non-self-explainers (mean = 4.48, SD = 2.18), ($F(1,44) = 26.47$, MSE = 6.52, $p < 0.001$, $\eta_p^2 = 0.38$). However, the impact of increasing coherence manifested as a trend ($F(1,44) = 3.27$, MSE = 6.52, $p < 0.08$, $\eta_p^2 = 0.07$) with maximum coherence (mean = 7.04, SD = 3.75) higher than minimum (mean = 5.71, SD = 2.56).

### 4.1.3. Time spent studying material

There was a significant main effect of self-explanation condition on time to read ($F(1,44) = 31.61$, MSE = 98.98, $p < 0.0001$, $\eta_p^2 = 0.42$), with participants in the self-explanation condition taking significantly longer to study the material (mean = 33.54, SD = 14.49) than participants in the non self-explanation condition (mean = 17.39, SD = 8.13). There was also a significant main effect of text coherence on time to read ($F(1,44) = 17.49$, MSE = 98.98, $p < 0.001$, $\eta_p^2 = 0.28$) with participants reading text of maximal coherence taking significantly longer to study the material (mean = 31.48, SD = 15.76) than participants studying minimally coherent text (mean = 19.47, SD = 9.42) (Table 5).[1]

Given that the maximally coherent text was a lot longer that the minimal text, it is unsurprising that it took longer to read. Consequently, in common with much work on text comprehension, reading times per word were computed. Analysis revealed main effects of self-explanation ($F(1,44) = 90.76$, MSE = 7.37, $p < 0.001$, $\eta_p^2 = 0.67$), with self-explanation associated with significantly higher times per word (mean = 1.07, SD = 0.51) than those who did not self-explain (mean = 0.28, SD = 1.68). There was also a significant effect of coherence ($F(1,44) = 29.36$, MSE = 2.39, $p < 0.001$, $\eta_p^2 = 0.40$). Participants who read minimal text spent significantly longer per word (mean = 0.90, SD = 0.63) than those with maximal text (mean = 0.45, SD = 0.33). Finally, there was also an interaction between self-explanation and text coherence ($F(1,44) = 8.65$, MSE = 0.70, $p < 0.005$, $\eta_p^2 = 0.16$). Simple main effects analysis revealed that self-explainers read for longer with minimally rather than maximally coherent text ($F(1,44) = 35.19$, MSE = 2.85, $p < 0.001$) but that non-self-explainers did not ($F(1.44) = 3.06$).

Given this difference, the learning outcome analyses were recomputed with time reading per word as a covariate. Analysis was by [2 by 2 by 2] MANCOVA with time per word as covariate and dependent variables of multiple choice, definition and blood-path diagram questions. This did not effect multivariate interaction between self-explanation condition and learning ($F(3,41) = 2.88$, $p < 0.05$). Univariate analyses showed self-explanation improved performance on multiple choice questions ($F(1,43) = 4.41$, $p < 0.05$), whilst the results for blood-path diagrams and definition questions manifest as trends ($F(1,43) = 3.47$, $p < 0.07$) and $F(1,43) = 3.04$, $p < 0.09$). Analysis on the post-test only data by [2 by 2] MANCOVA with time per word as covariate and dependent variables of implicit questions and knowledge inference questions confirmed the multivariate effect of self-explanation ($F(2,42) = 4.74$, $p < 0.014$) and the effect of coherence ($F(2,42) = 4.18$, $p < 0.022$). Univariate analysis showed that the knowledge inference questions that benefited from both self-explaining ($F(1,43) = 4.85$, $p < 0.033$) and from coherence ($F(1,43) = 3.84$, $p < 0.055$), whereas performance on implicit questions benefited from text coherence ($F(1,43) = 8.56$, $p < 0.005$).

### 4.1.4. Self-explanation measures

The statements made by participants in both the minimal and maximal text coherence conditions were transcribed and analysed (by the second author) according to the coding scheme described in Section 3.5. The first author recoded

[1] These data fail Levene's test of equal variance, however analysis of log transformed data produces identical results.

Table 5
Total study time (in min) and time per word (in seconds) by self-explanation and text coherence

| | Self-explainers | | | | Non-self-explainers | | | |
|---|---|---|---|---|---|---|---|---|
| | Max ($n = 12$) | | Min ($n = 12$) | | Max ($n = 12$) | | Min ($n = 12$) | |
| Study time | 41.92 | (14.59) | 25.17 | (8.57) | 21.04 | (8.28) | 13.76 | (6.39) |
| Time per word | 0.72 | (0.25) | 1.41 | (0.475) | 0.18 | (0.07) | 0.39 | (0.18) |

a random sample of 50% of the transcripts. Reliability between the codings assessed whether each statement was a self-explanation, paraphrase, a false self-explanation or a monitoring statement. Agreement between coders was judged to be sufficiently reliable ($K = 0.73$, $p < 0.001$).

The influence of text coherence on the verbalisations made by the participants was examined by a two-way between subjects MANOVA with dependent variables of total self-explanations, monitoring statements, paraphrases and words spoken (Table 6). The only significant effect was that students given minimally coherent text generated significantly more self-explanations ($F(1,22) = 9.13$, $\text{MSE} = 509.35$, $p < 0.01$, $\eta_p^2 = 0.29$). This was not a result of participants in the minimal coherence condition speaking more, as there were no differences between the conditions for overall number of words.

The number of each type of self-explanation in the two conditions (minimum or maximum coherence) was analysed by a two-way between groups MANOVA (Table 7). Reliability between the codings assessed whether each statement was a principle-based explanation, a goal-driven explanation, an elaborative explanation, a statement which noticed coherence, a negative monitoring statement, a positive monitoring statement or a false self-explanation. Agreement between coders was judged to be sufficiently reliable ($K = 0.79$, $p < 0.001$).

The minimal text coherence condition elicited significantly greater numbers of goal-driven explanations ($F(1,22) = 10.31$, $\text{MSE} = 152.08$, $p < 0.005$, $\eta_p^2 = 0.32$) and false self-explanations ($F(1,22) = 7.49$, $\text{MSE} = 6.81$, $p < 0.02$). There was also a trend for minimal coherence to increase the number of elaborative self-explanations ($F(1,22) = 3.70$, $\text{MSE} = 97.3$, $p < 0.07$, $\eta_p^2 = 0.14$).

In line with previous experiments (e.g. Ainsworth & Loizou, 2003; Renkl, 1997; Wolfe & Goldman, 2005) it was expected that different types of self-explanation would be differentially beneficial (Table 8).

Table 6
Number of self-explanations, monitoring statements, paraphrases and words by text coherence

| Statements | Max ($n = 12$) | | Min ($n = 12$) | |
|---|---|---|---|---|
| | M | SD | M | SD |
| Self-explanations | 22.7 | (20.4) | 50.5 | (24.5) |
| Monitoring statements | 4.1 | (5.8) | 3.2 | (3.8) |
| Paraphrases | 60.1 | (40.3) | 37.4 | (23.5) |
| Word count | 2003 | (1439) | 1845 | (888) |

Table 7
Types of self-explanation and monitoring statements by text coherence

| Statements | Max ($n = 12$) | | Min ($n = 12$) | |
|---|---|---|---|---|
| | M | SD | M | SD |
| Principle-based explanations | 0.75 | 1.71 | 1.83 | 1.53 |
| Goal-driven explanations | 8.00 | 7.03 | 24.17 | 16.0 |
| Elaborative explanations | 11.08 | 10.82 | 18.83 | 8.81 |
| Noticing coherence | 2.33 | 2.23 | 3.08 | 2.53 |
| Negative monitoring statements | 2.42 | 3.94 | 2.58 | 3.52 |
| Positive monitoring statements | 1.67 | 2.90 | 0.58 | 0.99 |
| False self-explanations | 0.50 | 0.80 | 3.42 | 3.61 |

Table 8
Correlation between types of self-explanation, paraphrase and monitoring statements and performance measures

| | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| (1) Total pre-test | 0.26 | 0.05 | 0.22 | 0.06 | 0.06 | −0.20 | −0.07 | −0.01 | 0.08 |
| (2) Total post-test | | 0.44* | 0.01 | 0.22 | 0.22 | −0.07 | 0.44* | −0.46* | 0.57** |
| (3) Principles | | | 0.75*** | 0.64*** | 0.36 | 0.21 | 0.56** | 0.14 | 0.1 |
| (4) Goals | | | | 0.69*** | 0.35 | 0.19 | 0.18 | 0.41* | 0.03 |
| (5) Elaborations | | | | | 0.62*** | 0.46* | 0.48* | 0.39 | 0.35 |
| (6) Coherence | | | | | | 0.16 | 0.29 | 0.18 | 0.41* |
| (7) Negative monitoring | | | | | | | 0.32 | 0.30 | 0.14 |
| (8) Positive Monitoring | | | | | | | | 0.18 | 0.07 |
| (9) False explanations | | | | | | | | | −0.10 |
| (10) Paraphrases | | | | | | | | | |

Note. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$ (two-tailed test of significance).

The only type of self-explanation to relate positively to total post-test scores was the number of principle-based self-explanations, however, surprisingly, the number of paraphrases also correlated with post-test scores. Those students who had a greater number of positive monitoring statements during the study phase also had higher post-test scores. Increased numbers of false self-explanations were associated with lower scores on the post-test. This analysis was repeated with reading time per word partialled out and the same pattern of results was found.

These correlations were also performed separately for each condition. This did not change the relationship between the processes measures and learning outcomes. However, it did reveal differences in the two conditions concerning the relation between monitoring statements and self-explanations. In the maximally coherent condition, positive and negative monitoring statements were associated with more principle-based explanations (negative 0.52, $p < 0.085$ and positive 0.95, <0.001), goal-based explanations (negative 0.69, $p < 0.013$ and positive 0.882, $p < 0.001$), elaborations (negative 0.69, $p < 0.013$ and positive 0.82, $p < 0.02$) and false self-explanations (positive 0.51, $p < 0.04$). In contrast in the minimally coherent condition, there was no relationship between monitoring statements and any self-explanation measure except false self-explanations (positive 0.81, $p < 0.001$).

## 5. Discussion

### *5.1. Does self-explanation and text coherence improve learning?*

#### *5.1.1. Self-explanation*

We expected the results of this study to confirm previous findings about the benefits of self-explanation and text coherence for low knowledge learners.

This experiment was consistent with prior research, which has shown that self-explanation is an effective strategy. Participants who had been trained to self-explain performed significantly better than participants who had not been trained to self-explain on all post-test questions (blood path diagram, definitions, implicit and knowledge inference questions) with the single exception of explicit multiple choice questions where both conditions performed equally well. If the results were recomputed controlling for reading time (per word) then this pattern of results remained essentially the same with the exception that multiple choice questions were answered better by participants who self-explained and that implicit questions were answered equally well.

This study therefore confirms the substantial literature showing that self-explanation is an extremely effective strategy, robust across a variety of domains (including text comprehension, mathematical problem-solving, computer application training), and both textual and pictorial representations (Ainsworth & Iacovides, 2005; Ainsworth & Loizou, 2003) and is not due simply to time on task (Renkl, 1997). Participants can be trained to self-explain under experimental conditions and do not need specific prompting to do so. Only two participants were observed to barely self-explain after training (both in the maximal coherence condition) with less than eight self-explanations. However, it should not be concluded that such a short training scheme will have long lasting changes on behaviour.

However, whilst using a self-explanation strategy resulted in an increase in post-test scores for the self-explanations conditions compared to non self-explanation controls, there was no significant correlation within the self-explanation groups between overall amount of self-explanation and subsequent post-test performance. Rather, results suggest that it is specific types of self-explanations that better predict subsequent test scores. The number of false self-explanations negatively correlated with post-test performance. This sounds self-evident, but in fact some studies have shown that learners can learn from erroneous self-explanations (e.g. Chi, 2000). The number of principle-based self-explanations correlated with post-test performance, which is in line with Ainsworth and Loizou (2003) and Renkl (1997).

The most striking difference between Ainsworth and Loizou (2003) and this study is that the number of goal-driven self-explanations did not correlate with learning outcomes. One possible explanation is that goal-driven explanations were significantly more common in the minimal text coherence and, we argue below, that self-explaining in this situation may be quite different to self-explaining when learning with coherent text or pictures as in Ainsworth and Loizou (2003).

The other surprising relationship found in this study was that an increased number of paraphrases was also associated with increased learning. This may be due to our definition of paraphrasing. Even if learners paraphrased by linking two or more sentences together, we still counted this as a paraphrase. In studies such as Chi et al. (1994) because learners only saw one sentence at time, this would be more likely to be coded as a self-explanation. Furthermore, in this study, participants who paraphrased were just as likely to give self-explanations as those who did not. However, in studies such as Chi et al. (1989) participants who paraphrased the text tended not to self-explain.

#### 5.1.2. Text coherence

Participants reading from maximally coherent text answered significantly more implicit questions successfully than did participants in the minimal text coherence condition. The same trend, although not statistically significant, was also apparent for the definition and knowledge inference questions. If the results were recomputed controlling for reading time (per word) then the benefits of text coherence remain – both implicit and knowledge inference questions were answered better in the maximal coherence conditions.

Students in the minimal coherence condition seemed to have to work harder to understand the material. Unsurprisingly, as the text in the maximal condition was nearly three times longer, overall reading times were longer with maximal text. However, when looking at reading times per word, minimal text learners took longer – replicating the findings of McNamara and Kintsch (1996).

The students in this study had not studied biological subjects past the age of 16 and were therefore considered to be low knowledge participants. Consequently, the benefits of maximal text coherence observed in this study are largely in accordance with previous research that reports novices who read a globally coherent and explanatory text demonstrate superior recall and have better mental representations of the material (e.g. Britton & Gulgoz, 1991; McKeown et al., 1992; McNamara & Kintsch, 1996; Vidal-Abarca et al., 2000). Text that provides all the information for ready comprehension enables the most efficient learning, perhaps by allowing novices to form a sufficiently detailed knowledge base with which to answer subsequent questions (McNamara et al., 1996).

The coherent text advantage in this study was most notable in implicit and knowledge inference questions, which are proposed to measure a situational level of understanding of the text. However, McNamara et al. (1996) found that performance in textbase questions also showed a significant benefit from maximum text coherence, whereas this study reveals no such effect. Identifying how text coherence will benefit learners will depend on a complex interrelationship between such factors as learners' prior knowledge, text difficulty, type of comprehension question, the strategies learners employ, goals for reading the material and reading skills (e.g. Gilabert et al., 2005; McNamara, 2001).

### 5.2. How does text coherence impact upon the self-explanation effect?

It was observed that there were significantly fewer self-explanations generated when reading from a maximally coherent text (mean 22.67) compared to a minimally coherent text (mean 50.5). A more fine-grained analysis revealed that this difference was primarily due to goal-driven, elaborative and false self-explanations. Thus, this study shows that designing material in such a way as to increase the number of self-explanations in fact harms learning. This requires some explaining as previous studies have shown that designing material to increase the number of self-explanations can improve learning (Ainsworth & Loizou, 2003; Renkl, 1997).

Generally, self-explanations in the minimal text condition occurred more frequently following text structure omissions such as, ''the heart is a muscular organ that pumps blood through the body'', compared to the equivalent elaborated text version containing connective links; ''the heart pumps blood through the body. Therefore it is necessary that the heart is a muscular organ''. So consequently it can be seen that a participant's self-explanation in the minimal text condition was "*That's a muscular organ, so it's got to be a muscle so that it is strong enough to pump blood around the whole body*". Similarly, a self-explanation was also more likely to be generated following a content structure omission in the text such as; "the septum divides the heart lengthways. The right side pumps blood to the lungs. The left side pumps blood to the other parts of the body", compared to the maximal coherence version containing a descriptive elaboration; "the septum plays an important role in preventing the mixture of the blood between the two sides of the heart", Thus, the participant's subsequent self-explanation "*The heart being divided lengthways, is probably quite important because just to keep the different blood separate, deoxygenated and oxygenated*" can again be seen as providing the explanation already elaborated in the maximal condition. Consequently, in the minimal text conditions learners are often generating the explanations that are given in the maximal condition.

Furthermore, the greater frequency of self-explanations made in the minimal text coherence condition may be regarded as evidence of additional processes used by the learner in order to resolve confusions in their understanding because of gaps in the textbase. This often resulted in a goal-based self-explanation. For example, after the minimal text description of valves as flap of tissue a typical participants' response was "*Flaps of tissue, I assume cause you need it to close behind after you have finished so that there is no leakage of whatever*." Additional support for this hypothesis is given from the observation that a significantly greater number of false self-explanations were made in the minimal text coherence condition. For example after having read that gases and molecules travel in straight lines, a response was "*They travel in straight lines, I assume to get through the body ok*" and concerning the functioning of the septum "*Septum acts as like a valve only allowing blood to travel in one direction through the heart*". Unsurprisingly, low knowledge participants learning from a text of minimal local and global coherence experienced more difficulty in comprehending the material than those reading from a maximally coherent version.

In contrast, participants in the maximal text conditions are producing self-explanations from an already well-elaborated text. When they self-explain they do so from a position of greater understanding. For example, after "This means oxygen and nutrients from the blood, travel through the capillary wall and in to cells. This process is called diffusion.", a participant explained, "*So oxygen and nutrients travel through the capillary wall. I am guessing that wastes would also go through this wall, I would think that this was diffusion as well because there is less waste on the other side*". Or "Hepatic portal circulation supplies blood through the digestive tract and liver" followed by "*You also need to get the blood circling around the digestive tract to get the nutrients circling in the blood*".

These differences seem to mirror the two different knowledge building mechanisms that Chi (2000) proposes for the self-explanation effect: (a) self-explanations support new inferences to overcome the limitations of the text, and (b) self-explanations can help learners detect flaws in their mental models and repair them. Under this view, participants in the minimal text condition are generating more self-explanations to overcome gaps. This is not controversial as we designed the text to be full of such gaps. However, self-explanations in maximal text condition should not be used to resolve text gaps, as the text was written to remove (or reduce) them. Consequently, maximal coherence may be more likely than the minimal coherence to induce self-explanations that help learners detect and repair faults in their mental models. Although the evidence for this statement is tentative, one source of support is the relationship between monitoring and self-explaining in the two conditions. Chi (2000) found that when self-explanations were involved in repair of mental models they were associated with monitoring statements – specifically negative monitoring related to the detection of mental model faults. In the minimal text condition, there is almost no relation between monitoring and explaining. However, in the maximal text condition, increased self-explanation was also associated with increased negative monitoring (as predicted by Chi). It was also associated with increased positive monitoring and in this case it seems to relate not to the detection of faults in participants' mental model, but their repair, as in "*Ah I think I am understanding why it has to have four chambers now*".

## 6. Conclusion

This research confirms previous studies showing that learners who are trained to self-explain perform better than those who have not been trained. It also confirms that novices learn better from a maximally coherent text. Effect size analysis suggests that self-explanation training had a greater positive impact on learning than providing coherent text. However, the results of the current study lead to the additional conclusion that whilst the use of a self-explanation strategy may facilitate learning, a greater frequency of self-explanations does not necessarily lead to enhanced learning gains. It was observed that participants studying from a minimally coherent text performed at a lower standard than those learning from a maximally coherent text, despite generating significantly more self-explanations. Thus, it seems that high quantities of self-explanations are not sufficient to counteract the negative effects on novices of a lack of text coherence on learning. Self-explanation and increasing coherence of text for novices are therefore two independent routes by which learners can be supported.

The results of the current study are in line with the findings of Gilabert et al. (2005), Kintsch and Kintsch (1995), and Loxterman, Beck, and McKeown (1994) who found that novice learners benefit most from coherent textual material if they actively process it. Furthermore, it also aligns with the one of the proposed explanation for the benefits of diagrams in supporting self-explanation – namely that diagrams by the dual processes of reducing cognitive effort and graphically constraining learners' interpretation of the situation, will encourage self-explanations. The coherent text performs a similar role in that it reduces the amount of effort participants need to expend to understand the material. The explicitness of the text is very similar to some of the ways that diagrams constrain learners' understanding. For example, the diagrams used colour to reduce the need for students to remember whether blood at a particular point in the system was oxygenated or deoxygenated. The coherent text provided similar support by its use of descriptive elaborations. For example, compare the sentences "The right side pumps blood to the lungs. The left side pumps blood to the other parts of the body." The maximal version includes the phrase "the left side of the heart contains oxygenated blood (from the lungs), the right side of the heart contains deoxygenated blood (from the body)". Moreover, diagrams support the construction of mental models (Schnotz, 2002). Given the potential differences in the functions of self-explanation in the two different conditions (gap filling in the minimal text condition and mental model detection and repair in the maximal condition), this again suggests that maximal text is acting like diagrams to support self-explanation.

Further work is now required to expand these findings from laboratory situations to students reading to learn in more natural situations. Here, there is a range of other strategies for learners (such as note taking, asking questions, and integrating material from multiple texts), learners will have more varied motivations and goals for studying (e.g. Lindblom-Ylanne & Lonka, 1999) and texts will not be as extreme in their coherence. More work is therefore required to understand how text coherence impacts on learners who spontaneously chose to self-explain. However, this study suggests that rather than designing material, which, by its poverty of coherence, will drive novice learners to engage in sense-making activities in order to achieve understanding, we should design well-structured, coherent material and then encourage learners to actively engage with the material by using an effective learning strategy.

## Appendix 1. Minimally coherent text (first 20% of the text)

1. Human life depends on the distribution of oxygen, hormones and nutrients to the cells in all parts of the body.
2. It depends on the removal of carbon dioxide and other wastes.
3. These tasks are partially carried out by the circulatory system (the heart, a network of blood vessels, and blood).
4. The blood acts as a transport medium for oxygen, nutrients, and other substances.
5. The heart is the muscular organ that pumps blood through the body.
6. It consists of cardiac muscle, nervous tissue and connective tissues.
7. The septum divides the heart lengthwise.
8. The right side pumps blood to the lungs.
9. The left side pumps blood to the other parts of the body.
10. Each side of the heart is divided into an upper chamber (atria) and lower chamber (ventricle). Blood flows from upper to lower chamber.
11. One-way valves separate the chambers.
12. They prevent blood from moving in the wrong direction.
13. The atrio-ventricular valves (a-v) separate the atria from the ventricles.
14. The right side valve is the tricuspid valve.
15. The left side valve is the bicuspid valve.
16. Blood also flows out of the ventricles.
17. Two semi-lunar (s-l) valves separate the ventricles from the large vessels.
18. Blood flows out of the heart.
19. They consist of flaps of tissue.
20. They open as blood is pumped out.

21. Blood returning to the heart has a high concentration, or density, of carbon dioxide and a low concentration of oxygen.
22. It enters the right atrium.
23. The atrium pumps it through the tricuspid valve into the right ventricle.
24. The muscles of the right ventricle contract.
25. Blood is forced through the right semi-lunar valve.
26. It travels into the vessels leading to the lungs.
27. In the lungs, carbon dioxide leaves the circulating blood and oxygen enters it.
28. The oxygenated blood returns to the left atrium.
29. It is pumped through the bicuspid valve into the left ventricle.
30. The muscles of the left ventricle contract.
31. Blood is forced through the semi-lunar valve, into a large blood vessel.
32. Blood travels throughout the body.

## Appendix 2. Maximally coherent text (first 20% of the text)

*The circulatory systems role in supplying and removing substances from cells of the body*

1. Human life depends on the distribution of oxygen, hormones and nutrients to the cells in all parts of the body and on the removal of carbon dioxide and other wastes.
2. These tasks are partially carried out by the circulatory system, which consists of the heart, and an intricate network of blood vessels that carries blood (so that blood reaches cells in all parts of the body supplying essential nutrients and removing waste).
3. The blood moves through the vessels of the circulatory system and serves as the transport medium for oxygen, nutrients, as well as other substances such as carbon dioxide and waste products made in the cells.

*The structure of the heart: two halves, four chambers and two sets of valves*

4. The heart pumps blood through the body.
5. The pumping of blood is achieved by contraction of the cardiac muscles in the heart.
6. Therefore, it is necessary that the heart is a muscular organ capable not only of contracting, but also of contracting with enough power to force blood around the body.
7. The heart consists of cardiac muscle, nervous tissue and connective tissues.
8. Although the heart is a single organ, it can be separated into two halves.
9. Each half consists of two chambers.
10. The division of the heart lengthways is created by the septum.
11. The right side of the heart pumps blood to the lungs and the left side of the heart pumps blood to the other parts of the body.
12. The septum plays an important role in preventing the mixture of blood between the two sides of the heart.
13. This is important because the left side of the heart contains oxygenated blood (from the lungs), whereas the right side of the heart contains deoxygenated blood (from the body).
14. Each side of the heart is divided into an upper and lower chamber.
15. The upper chambers are called the atrium and the lower chambers are called the ventricles.
16. In each side of the heart blood flows from the atrium (the upper chambers) down to the ventricle.
17. One-way valves separate these chambers.
18. These valves only allow blood to flow in one direction (from upper to lower chambers) and so prevent blood from moving in the wrong direction.
19. This is important to maintain the one-way directional flow of blood through the body, allowing cells to be supplied with oxygen and other nutrients and have waste products removed.
20. The atrio-ventricular valves (a-v) are the one-way valves that separate the atria (the upper chambers of the heart) from the ventricles (the lower chambers of the heart).

21. The a-v valves are found between the upper and lower chambers on both the right and left sides of the heart.
22. The valves perform the same function, but are given different names: the a-v valve on the right side is the tricuspid valve, and the a-v valve on the left is the bicuspid valve.
23. Blood in the heart flows from the upper chambers (atrium) to the lower chambers (ventricles) and then flows out of the heart.
24. Like the a-v valves that ensure the downward flow of blood from the atrium to ventricles, valves are also found between the ventricles and the vessels through which blood leaves the heart.
25. The valves that separate the ventricles from these large vessels that take blood away from the heart are called the semi-lunar (s-l) valves.
26. Each of the semilunar valves consists of flaps of tissue.
27. These flaps only open when the ventricles contract to pump blood out of the ventricles, enabling blood to leave the heart.
28. The flaps remain closed until the ventricles are full of blood ready to be pumped out of the heart.
29. If the valves were always open there would be back-flow of blood from the blood vessels to the ventricles.

*The flow of de-oxygenated blood returning to the right side of the heart*

30. Blood returning to the heart from the body has a high concentration, or density, of carbon dioxide and a low concentration of oxygen.
31. This is because as the blood travels round the body, cells take up oxygen to use in cellular processes and release carbon dioxide (which is a waste product of such processes) back in to the blood.
32. This means that after travelling round the body, the blood is de-oxygenated.
33. Such blood from the body enters the right atrium.
34. The atrium pumps this blood down through the tricuspid valve (the atrio-ventricular valve separating the atrium and ventricle of the right side of the heart) into the right ventricle.
35. A similar process occurs from the ventricles to the vessels that carry blood away from the heart. The muscles of the right ventricle contract.
36. The right semilunar valve opens because ventricles are contracting.
37. The contraction of the right ventricle squeezes blood from this chamber through the right semi-lunar valve into the vessels carrying blood away from the heart.
38. The vessels on the right side of the heart carry blood (which has been around the body) to the lungs.

*The flow of oxygenated blood back to the left side of the heart*

39. In the lungs, carbon dioxide that has been collected from cells as blood has been pumped around the body, leaves the circulating blood and oxygen enters it from the lungs.
40. This means that the blood is now oxygenated.
41. This oxygenated blood returns to the heart.
42. However this time the blood enters the left atrium.
43. This oxygenated blood is then pumped through the bicuspid valve (the a-v valve on the left side of the heart) from the atria into the left ventricle.
44. Just as is the case with the right side of the heart, strong contractions of the muscles of the left ventricle then force the blood through the semi-lunar valve, into a large blood vessel.
45. The large blood vessel from the left side of the heart directs blood (that is now oxygenated) throughout the body.

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