The Effects of Self-Explaining When Learning with Text or Diagrams

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Abstract

Previous research has demonstrated that self-explaining is an effective metacognitive strategy that can help learners develop deeper understanding of the material they study. In this paper, we report an experiment that explored if the format of material (ie. text or diagrams) influences the self-explanation effect. Twenty subjects were presented with information about the cardio-vascular system and prompted to self-explain as they learnt; ten received this information in text and ten in diagrams. Results showed that students given diagrams performed significantly better on post-tests that students in the text conditions. Diagrams students also generated significantly more self-explanations that text students. Furthermore, the benefits of self-explaining were much greater in the diagrams condition. The results are interpreted with reference to multiple differences in the semantic, cognitive and affective properties of the text and diagram representations used in this study to identify why diagrams can promote the self-explanation effect.

Introduction

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; Reimann & Neubert, 2000; Renkl, 1997; Renkl, Stark, Gruber, & Mandl, 1998).

In the original study, Chi *et al* (1989) gave subjects learning mechanics three worked-out examples containing text and diagrams to study. Students who spontaneously generated a large number of self-explanations (SEs) scored over twice as highly on a post-test as those who gave few explanations. High SE students also demonstrated better monitoring of their own understanding. Subsequently, a number of studies have confirmed this effect and examined the scope of its application. For example, the benefits of self-explaining are not only present when students spontaneously generate explanations. Students who are prompted to give self-explanations also profited from this strategy (Chi, *et al*, 1994). 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. Furthermore, computer coaches can be successful at prompting students to self-explain. Conatti and Van Lehn (2000) implemented an SE-Coach, which scaffold learners' attempts to self-explain as they learn physics problems. They observed that novice learners benefit from structured help for self-explaining whereas experts need less support - a finding consistent with the significant literature on scaffolding (*e.g.* Wood, Bruner & Ross, 1976; Bruner, 1986). Aleven & Koedinger (2002) found that the effectiveness of an intelligent tutoring system that supports the learning of geometry could be further improved by adding a simple interface that required students to explain the problem solving principle involved in a solution step.

It is evident that these effects are observed in a wide variety of domains (*e.g.* physics problem solving (Chi *et al*, 1989; Conatti & Van Lehn, 2000) probability (Renkl, 1987); cardio-vascular system (Chi, *et al*, 1994; Chi, Siler, Jeong, Yamauchi, & Hausmann, 2001), geometry (Aleven & Koedinger, 2002), Lisp Programming (Bielaczyc *et al*, 1995), and spreadsheets (Reimann & Neubert, 2000). Therefore, we know the beneficial effects of self-explanations can be found for both procedural and conceptual domains, can promote analogical transfer (Neumann & Schwarz, 1998) and are not limited to learning from examples. However, one question that has only received only limited attention is the whether the way that material is represented (*e.g.* in text or in diagrams) influences learners' self-explanations. The studies described above have either presented material as text (*e.g.* Chi *et al,*1994) or as a combination of text and diagrams (*e.g.* Aleven & Koedinger, 2002; Chi *et al*, 1989). Yet, there is considerable evidence to suggest that presenting information as either text or diagrams has considerable influence on learning. In this paper, we describe a study that compared the self-explanations that students made while learning about the cardio-vascular system when the same information was presented either as text or as diagrams. This research examined whether the form of representation influenced the number and type of self-explanations and whether there were differential benefits of self-explaining for these alterative forms of representation.

Learning with text or diagrams

There is abundant evidence that the way in which information is presented can influence learning and problem solving. Probably the most common distinction is between graphical representations, which explicitly preserve geometric and topological information, and textual representations that have an arbitrary relationship to the object that they represent (*e.g.* Peirce, 1906; Larkin & Simon, 1987; Schnotz, 2002). It is known that representing the same information either as text or graphically in diagrams can result in different inferential processes even when the representations are information equivalent (*i.e* information from one representation is derivable from the other and *vice versa*).

Scaife & Rogers (1996) proposed three ways that representations differ in their advantages for learning. Firstly, some representations facilitate computational offloading - the extent to which different external representations reduce the amount of cognitive effort required to solve informationally equivalent problems. Typically, graphical representations are considered to load highly on these favorable attributes. For example, Larkin & Simon (1987) contrasted interpretation of graphical and textual representations in terms of search, recognition and inference. Analyzing a physics pulley example, they show how search processes are considerably more efficient in diagrammatic rather than sentential representations. With a more complex geometry example, the representations differ in terms of cost of recognition. They propose that textual representations have a high cost of perceptual enhancement when compared to the diagrammatic representations. Thus, the diagrams in these situations reduced the cognitive effort required to make the necessary inferences.

Scaife & Rogers's second factor is re-representation - the way different external representations, that have the same abstract structure, influence problem solving. For example, Zhang (*e.g.* Zhang & Norman, 1994, Zhang, 1997, 1999) analyses the efficiency of a representation in terms of the interaction between internal and external processing. This is illustrated by Zhang & Norman (1994) who showed that isomorphic versions of the Towers of Hanoi problem were solved faster and with fewer errors when subjects were given representations that externalized more of the information. Such an analysis predicts performance on a wide range of tasks (*e.g.* number comparison, cockpit information). This approach has not been widely used to compare text and graphics, as the focus tends to be on how alternative forms of graphical representation externalize information. Nevertheless, given the emphasis on perceptual processes rather than cognitive operations, it is clear that graphical representations will often be found to be more effective by this account.

The third factor that Scaife & Rogers propose influences learning and problem solving with representations is graphical constraining - the limits on the range of inferences that can be made about the represented concept. Stenning and Oberlander (1995) argue that textual representations permit expression of ambiguity in the way that graphical representations do not. It is this lack of expressiveness that makes graphical representations more effective for problems that are determinate (*e.g.* Bauer & Johnson-Laird, 1993; Cox & Brna, 1995).

The point of this review is not to confirm the often-stated intuition that graphical representations are "better" than textual representations as in some situations textual representation is found to be superior (*e.g.* Green & Petre, 1992). But instead to show that if information is presented as either text or graphics, it affects the processes and outcomes of learning and problem solving. Furthermore, in line with the "match-mismatch" conjecture of Gilmore & Greene (1984), research suggests that performance is most likely to be facilitated when the structure of information required by the problem matches the form provided by the representational notation.

Text, Diagrams and Self-Explanation

Although the influence of the format of material on self-explaining has not previously been directly explored, the role of self-explanations when learning with diagrams has been considered. Cox (1999) and Brna, Cox & Good (2001) propose that diagrams will facilitate the self-explanation effect. They argue that as graphical representations act to constrain the interpretation of a situation by limiting abstraction, they provide learners with more salient and vivid feedback to compare against their explanations. However, Wilkin (1997) argues that diagrams may inhibit the self-explanation effect. She presented subjects with worked-out examples in text from which they had to draw diagrams of the two-dimensional motion described. In contrast to previous research, she found no benefit of self-explaining. She concluded that diagrams, by invoking familiar but erroneous knowledge, encouraged students to generate incorrect self-explanations. Her results do not show that diagrams *per se* will inhibit self-explanation, only that if learners misinterpret any form of representation and use that as the basis of self-explanations, then they may not profit by the activity. As such it points to a role for a tutor in guiding students self-explanations (*e.g.* Chi *et al*, 2001).

Self-explaining has also been considered in the context of learning as multi-representational understanding. Aleven & Koedinger (2002) argue that self-explanations may be particularly beneficial if they help in the integration of visual and verbal knowledge. Novice learners of geometry lack the diagrammatic reasoning schemas of experts (Koedinger & Anderson, 1990) and rely solely on visual information in problem solving with fragmented and separate visual and verbal declarative knowledge. Self-explaining helps these learners to strengthen their verbal declarative knowledge and integrate it with visual knowledge leading to deeper understanding of the problem. Cox (1999) proposes that translation across modalities (*e.g.* given verbal explanations when viewing or constructing graphical representations) will lead to greater understanding than translating between representations in the same modalities (*e.g.* written text and verbal explanations).

This study set out to answer a number of related questions about the role of self-explaining when learning about the cardio-vascular system from either text or diagrams. (1) Do students learn more when they study diagrams or text? We hypothesized that the domain would be better understood through diagrams rather than through text. Although we reject the “graphical superlativism” position, much of the reasoning about the cardio-vascular system involves the relation of structural and functional information that ultimately should be fused into a coherent mental model. There are good reasons to suppose that this process will be facilitated more by the diagrams than by the text (*e.g.* Cox

& Brna, 1995; Glenberg & Lawson, 1992; Mayer, 1993; Schnotz, 2002). (2) Do students learn more when they self-explain? In line with the majority of previous work on learning with text and diagrams, we expect students learning to positively relate to the number of self-explanations they give. (3) Do students generate more self-explanations when they study diagrams or text? Given the expected facilitatory effects of diagrams on the processes of learning, we anticipate that students will give more self-explanations when they learn with diagrams rather than text. Students will be provided with concrete diagrams, which by the dual processes of reducing cognitive effort and graphically constraining learners' interpretation of the situation will encourage self-explanations. (4) Is self-explanation more beneficial for learning from diagrams or text? Predictions by Cox and Aleven & Koedinger would suggest that verbal self-explanations should encourage greater understanding in the diagrams condition as this will encourage learners to integrate visual and verbal knowledge. In the text condition, the effect may not be as pronounced as both the material and self-explanations will use the same underlying form of representation (spoken or written text). However, given that diagrams are already predicted to improve learning in this domain, we may not notice any additional benefit for self-explaining around diagrams. Furthermore, a very large number of studies have pointed out the difficulties that learners face when translating between representations (*e.g.* Anzai, 1991; de Jong *et al*, 1998; Tabachneck-Schijf, Leonardo, & Simon, 1997) and this can be more difficult when representations are presented in different formats (Ainsworth, Bibby & Wood, 2002). Hence, there is good reason to believe that diagrams subjects should benefit from self-explanations, but only if their performance is not already at ceiling and if they can integrate their explanations and the diagrams.

Method

Design

The experiment had a two factor mixed design. The first factor, format, was a between groups measure, with two levels: whether participants studied diagrams or text. The second factor, time (pre-test, post-test), was a within groups measure. This resulted in two experimental groups, with ten participants in each group. Participants were randomly assigned to one of the two conditions such that each condition had the same number of males and females and the mean age of the participants did not differ.

Participants

Participants were twenty undergraduates (10 males and 10 females) volunteers ranging in age from 19 years to 23 years. None had studied subjects with a strong biological component (such as medicine, genetics, biology, *etc*) past the age of 16.

Materials

The Text

The passage about the human circulatory system used by Chi *et al* (1994, 2001) was adapted for this use in this study. 59 of the 86 sentences used in Chi (2001) were included; the remaining 27 sentences were deleted. The deleted sentences referred to ideas that could not be easily represented diagrammatically. Commonly, this was done where text would be required to supplement a diagram in such a way they would have conveyed most or all of the meaning (*e.g.* "You can feel this stretching of arteries as the pulse in the wrist" or "The English scientist William Harvey (1578 – 1657) first showed that the heart and blood vessels formed one continuous closed system of circulation"). No sentence was removed whose omission would have severely impaired the essence of the passage. The text was then divided into 13 structurally coherent sections. This is a departure from Chi *et al*'s studies where each sentence is presented separately. In this study, it was felt important to make the diagrams and text condition as similar as possible, so each section of the text corresponded to a single diagram.

Table 1

Contents of the material

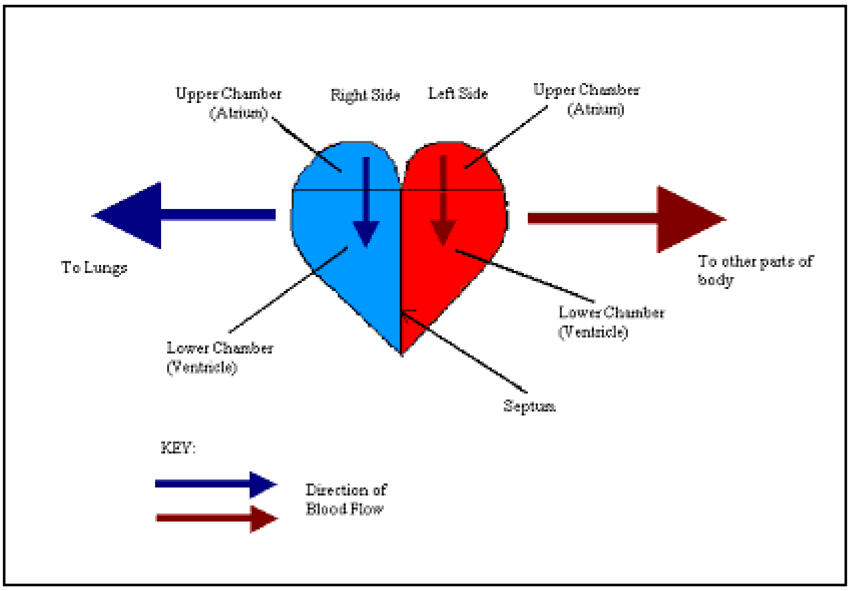
Order	Section Content
1.	The Human Circulatory System
2.	The Components of the Circulatory System
3.	A General Structure of the Heart
4.	The Blood Flow in the Heart
5.	Phases of Muscle Contraction
6.	Blood Vessels
7.	Structure of Blood Vessels
8.	The Process of Diffusion (I)
9.	The Process of Diffusion (II)
10.	Function of Valves
11.	The Two Primary Subsystems of Circulation (I)
12.	The Two Primary Subsystems of Circulation (II)
13.	Subsystems of Systemic Circulation

Each of the sections of the passage given a title, was printed on a separate sheet of paper and presented in a file in the order given in Table 1.

The Diagrams

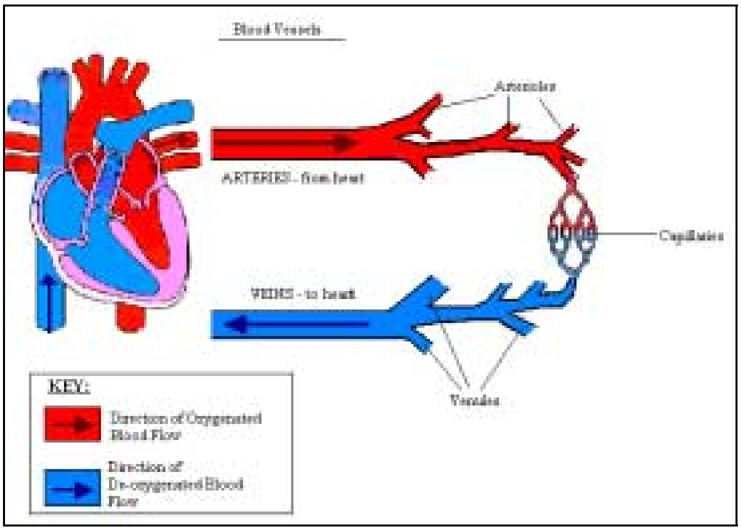
Thirteen diagrammatic representations were constructed that corresponded to each section of the text. Piloting ensured that the information presented in the text was inferable from the diagrams. However, it is not possible to claim that the text and diagrams are informationally equivalent. The specificity of graphical representations enforces a concreteness that is not required by the text. For example, nowhere in the text states the relative size of the atria to the ventricles, but the information is inevitably present in the diagrams. This is not a flaw in the experimental design but a fundamental difference between text and concrete diagrams. No test item required learners to reason about information only inferable from the diagrams.

Each diagram is a mix of text and graphics with the graphics varying in their level of detail according to the need of the information to be represented. For example, an abstract representation is appropriate for “General Structure of the Heart” but a more concrete picture was used for “Blood Vessels”. The diagrams were constructed so that all the information was given either solely in the pictures or by requiring learners to integrate a piece of text with some aspect of the picture (*e.g.* direction of blood flow is given in red and blue with text explaining that red is oxygenated blood and blue de-oxygenated blood). Where relevant, the same labeling and colors were used across all thirteen diagrams. Ten diagrams included a key, which gave information such as the direction of blood flow, contracted and relaxed valves, and oxygenated and deoxygenated blood. Each of the diagrams was printed on a separate sheet of paper (note a single diagram could contain multiple graphics), given the appropriate heading and assembled in a file in the same order as the text. See Figures 1 and 2 for examples of sentences and diagrams used.



- The septum divides the heart lengthwise into two sides.
- The right side pumps blood to the lungs, and the left side pumps blood to other parts of the body.
- Each side of the heart is divided into an upper and lower chamber.
- Each lower chamber is called a ventricle.
- Each upper chamber is called an atrium.
- In each side of the heart blood flows from the atrium to the ventricle

Figure 1: General Structure of the Heart (Diagram and Text)



- The large, muscular vessels that carry blood away from the heart are called arteries.
- Blood travels through a network of smaller arteries, which in turn divide and form even smaller vessels called arterioles.
- The arterioles branch into a fan of tiny vessels called capillaries.
- De-oxygenated blood flows through capillaries that merge and form larger vessels called venules.
- Several venules in turn unite to form a vein, a large blood vessel that carries blood to the heart.

Figure 2. Blood vessels (Diagram and Text)

Pre-Tests and Post-Tests

The pre-test and post-test were based again based on those of Chi and her colleagues. Chi *et al*'s (2001) tests formed the ideal basis for these types of experiment as they was designed so that it is possible to identify what knowledge each question is assessing, and whether this knowledge has been directly given or whether a learner would have to infer it. The tests were adapted to address representational issues and the number of questions were reduced as the current experiment used less material.

Blood Path Diagram

Subjects were required to draw a blood-path on the outline of a human body at pre-test and post-test.

Explicit Questions

Ten questions can be answered by directly referring to either a passage in the text or (part of) a diagram. Half of the questions were presented diagrammatically and half textually. They took the form of multiple-choice questions where participants had to circle the correct answer out of four possible answers. Multiple choice was used as it was easier to set questions with diagrammatic solutions this way. As these questions were administered at pre and post-test, the mode of presentation (text/diagrams) was counterbalanced and varied between subjects.

Implicit Questions

For the post-test, six questions were developed that required the student to integrate information from two or more lines of the text, or from different parts of diagrams, or to integrate across nonconsecutive paragraphs (Chi *et al*, 1994) or diagrams. For example to answer question #1 Why is there an artery that carries deoxygenated blood? a student would have to integrate and reason from information explicitly stated in several sentences in the text or from different parts of diagrams. All questions were presented as text only and students had to write their answers. Each question was marked out of 2, giving a maximum score of 12 for implicit questions.

Knowledge Inference Questions

This category of questions consisted of 4 questions that required students to infer important new knowledge from the sentences or diagrams, "*e.g.* "Why do we sometimes refer to the heart as a 'doublepump'?". To acquire such a deep understanding of the materials presented required students to develop a correct mental model. All questions and their answers were written in text. Each question was marked out of 3, giving a maximum score of 12 for knowledge inference questions.

Procedure

Students worked individually with one experimenter to answer pre-test questions, study the material whilst self-explaining and the respond to post-tests. In total, the session took around one hour.

Pre-tests: As in Chi *et al*'s (1994) study, the experimenter gave students an outline of the human body and they were instructed to "draw the blood-path to all parts of the body." It was suggested that they could label the diagram or add a key if they wished. Secondly students were required to answer the multiple-choice questions.

Study Phase: Students were either given the text or diagrams file according to condition. It was explained that they would be presented with a series of texts or diagrams which explained/represented the human circulatory system. The instructions stated to self-explain while they read each sentence or while they studied different diagrams. Students were asked to generate explanations to themselves about what it was they were studying, and to try to understand the texts or diagrams. The experimenter prompted the students to self-explain when they became silent, or asked for further clarification if what they stated was vague. These prompts and self-explanations were audio taped.

Post-test: After studying the material, students immediately took a post-test. This consisted of the blood-path diagram and the multiple-choice questions from the pre-test, and in addition the six implicit questions and the four knowledge inference questions.

Coding of verbal protocols

The self-explanations produced by the students were coded using the following scheme. It is based on Renkl (1997) and modifications were made where necessary to adjust it to the domain and format of presentation. For example, the category of anticipative reasoning did not seem appropriate to this more declarative conceptual domain.

Principle-based explanation: This category was scored if participants made reference to the underlying domain principles in an elaborated way. Thus, mentioning "*this is diffusion*" would not be scored as self-explanation; participants would have to elaborate and say for example "*this is due to diffusion as molecules are spreading from a greater concentration to a lesser concentration*." This category corresponds to Renkl's (1997) coding of the learner's references to the principles of probability, and to Chi *et al*'s (1989) coding of the learner's references to Newton's Laws. It is primarily relevant in this study to the principle of diffusion.

Goal-driven explanation: Self-explanations were classified as goal-driven if the student imposed a goal or purpose for an action. For example saying, "*valves are needed because otherwise how would the blood go up? Because of gravity blood goes down*" would be attributing a purpose/goal to the opening and closing actions of the valves. Another example of a goal-driven explanation is inferring that the reason blood is being taken to the lungs is *"so that it can become oxygenated"*. This category corresponds to Chi's (1989) 'Impose a goal or purpose for an action' and Renkl's (1997) 'Goal-operators combinations' categories.

Refine or expand the conditions of an action: If a student produced explanations that inferred information from the present sentence/diagram then it was classified in this category. Elaborations assigned to this category included inferences regarding concrete material rather than principle-based explanations "*e.g.* the network begins from the heart and then blood goes through the network. It was also used to code metaphors and analogies ("*have you ever seen part of a road where cars move in both directions? No! Why should blood*").

Noticing Coherence: This category directly corresponds to that of Renkl's study and indicates when students realized the coherence of the stimuli by relating what they were presently studying to something they had studied before (*e.g.* "*it's just the same thing as before…just presented differently*".

Monitoring-negative: A statement indicating that the student did not understand the sentence/diagram or part of a sentence/diagram was assigned to this category (*e.g.* "*I do not understand what this means*").

Monitoring-positive: If the student indicated an understanding of the text/diagram, for example, "*Okay, I see what this is about*" then this was referred to a monitoring positive statement.

Results

Do students learn more when they study diagrams or text?

Learning was assessed using four types of test. Blood path diagram and multiple-choice questions were given at both pre-test and post-test, implicit questions and knowledge inference questions at post-test only.

To examine the effects of condition on change in students' knowledge, two [2 by 2] ANOVAs were carried out on the blood path diagram and multiple–choice questions. The design of the analysis was 2(diagrams, text) by 2(pre-test, post-test).

Table 2
Scores for Blood-Path Diagram and Multiple-Choice Questions by Format and Time

	Blood Path Diagram (out of 9)				Multiple-Choice (out of 10)			
	Diagrams (n=10)		Text (n=10)		Diagrams (n=10)		Text (n=10)	
	M	SD	M	SD	M	SD	M	SD
Pre Score	2.4	0.70	2.4	0.84	3.5	1.18	3.8	1.62
Post Score	6.2	1.81	3.4	1.35	8.0	1.56	5.6	2.01

Blood path diagram

Analysis revealed significant main effects of time ($F(1,18)=45.47$, $MSE = 1.27$, $p<.0001$) and condition ($F(1,18)=10.38$, $MSE = 1.89$, $p<.01$) modified by a significant interaction between condition and time ($F(1,18)=15.47$, $MSE = 1.89$, $p<.001$). Simple main effects showed the only significant difference between the conditions was at post-test ($F(1,36) = 24.85$, $MSE = 1.58$, $p<0.001$), as subjects in the diagram condition scored significantly higher than subjects in the text condition (Table 2). Scores in diagram condition significantly improved over time, from pre-test to post-test, ($F(1,18) = 57.00$, $MSE = 1.27$, $p<0.001$), whereas the improvement for the text condition manifested as a trend ($F(1,18) = 3.95$, $MSE = 1.27$, $p=0.063$).

Multiple-Choice Questions

There was a significant main effect of time ($F(1,18)=89.08$, $MSE = 4.14$, $p<.0001$) and a significant interaction between condition and time ($F(1,18)=16.36$, $MSE = 1.11$, $p<.001$). Simple main effects analysis ($F(1,36) = 10.97$, $MSE = 2.63$, $p<0.003$) showed the only significant difference between the conditions was at post-test, where the diagram condition scored significantly higher. Scores in both conditions improved over time, from pre-test to post-test - diagrams ($F(1,18) = 91.00$, $MSE = 1.11$, $p<0.001$) and text ($F(1,18) = 14.54$, $MSE = 1.11$, $p<0.002$).

Implicit Questions

Table 3 shows the scores for the questions presented only at post-test, the implicit and knowledge inference questions.

Table 3
Scores for Implicit and Knowledge Inference Questions by Format

	Implicit Questions (out of 12)				Knowledge Inference (out of 12)			
	Diagrams (n=10)		Text (n=10)		Diagrams (n=10)		Text (n=10)	
	M	SD	M	SD	M	SD	M	SD
Post Score	7.4	1.26	5.9	2.02	9.4	1.78	5.6	1.96

There was a trend towards significance between condition, ($F(1,18) = 3.95$, $MSE = 2.85$, $p = .062$) with students in the diagrams condition scoring somewhat higher on implicit questions.

Knowledge Inference Questions

Format had a significant influence on the knowledge inference questions, ($F(1,18) = 3.95$, $MSE = 3.49$, $p<0.001$) with scores in diagram condition significantly higher than the text condition.

Summary

Overall, although there are no measurable differences in their prior knowledge, students presented with materials in a diagrammatic format are performing significantly better at post-test than those given the information textually.

Do students who self-explain more perform better?

Whilst the students were studying the material, they were encouraged to self-explain and these explanations were then transcribed and analyzed. The second author coded all statements into either a type of self-explanation, monitoring statement or other phrase, which was almost always a paraphrase with the occasional off topic comment. These data are shown in Table 6. The first author recoded 60% of the transcripts (a total of 853 statements). Reliability between the codings was assessed by examining whether each statement was a self-explanation, a monitoring statement or other statement. Agreement between authors was found to be reliable ($K=0.91$, $p <0.001$).

Table 4
Correlations between number of self-explanations, total time spent learning, number of words, pre- and post-test scores

	2	3	4	5
(1) Num. SEs	-.06	.11	-.19	.50*
(2) Total Time		.67**	-.26	-.69**
(3) Num. Words			-0.03	-.50*
(4) Pre-test total				.10
(5)Post-test total				

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

In line with previous experiments, we expected students who generated a greater number of self-explanations to perform better at post-test. This is what we observed (Table 4). This is not because students with higher number of self-explanations spent a greater time learning the material nor is it because they generally spoke more. In fact, students who took longer to study the material, performed worse at post-test. In addition, an explanation that students generating more self-explanations did so because they were more familiar with the material can be rejected as there was no significant relationship between pre-test scores and number of self-explanations. It is also interesting to note that pre-test performance does not correlate with post-test scores.

Do students generate more self-explanations when they study diagrams or text

Table 5

Mean Number of Self-Explanations, Number of Monitoring Statements ,Number of Words, and Time to Learn by Format

	Diagrams (n=10)		Text (n=10)	
	M	SD	M	SD
Total SEs	10.7	3.97	6.4	3.83
Total Monitoring	1.2	1.23	1.1	1.28
Number of Words	909.0	215.8	1205.4	197.8
Time to Learn (Minutes)	15.9	2.33	24.4	5.01

The impact of format on the processes of learning was examined by 2 way MANOVA with dependent variables of Number of Self-Explanations, Number of Words and Time to Learn. The format of instruction had a significant influence on the number of self-explanations generated ($F(1,18) = 6.06$, $MSE = 15.25$, $p<0.025$). Students in the diagram condition generated significantly more self-explanations that those studying text. However this was not because they spent longer learning the material as students in the text condition studied the material significantly longer than diagrams students ($F(1,18) = 23.62$, $MSE = 15.29$, $p<0.001$). Nor was it because they spoke more, as the number of words spoken by students in the diagrams condition was significantly less than in the text condition ($F(1,18) = 10.26$, $MSE = 42832$, $p<0.05$). A Mann-Whitney test on the total number of monitoring statements revealed no impact of format ($U = 46.5$). Overall, it would seem that the diagrammatic format encouraged students to generate more self-explanations but this did not occur at the cost of making learning any less efficient.

To confirm that this was not an individual differences effect, a median split on the number of self-explanation explanations was used to create two categories: high self-explainers (eight or more explanations) and low self-explainers (7 or less explanations). Table 6 shows this distribution with respect to condition.

Table 6

Number of High and Low Self-Explainers by Format

	Diagrams	Text
High	7	2
Low	3	8

Fisher's exact test confirmed that this distribution was not random ($p<0.035$, one sided). There were significantly more high self-explainers in the diagrams condition and low self-explainers in the text condition than would have been expected by chance.

Table 7

Mean Number of Types of Statements by Condition

	Diagrams (n=10)		Text (n=10)	
	M	SD	M	SD
Principle Based	0.7	0.67	0.0	0.00
Goal Driven Explanation	7.7	3.47	4.3	2.26
Refine Conditions	1.6	0.84	1.4	2.07
Noticing Coherence	0.7	0.67	0.7	0.67
Monitoring Negative	0.5	0.71	0.9	1.20
Monitoring Positive	0.7	0.67	0.2	0.42

The number of each type of self-explanation was analyzed by a 2 way between groups MANOVA (diagrams, text) with the following dependent variables: goal driven explanations, refine conditions of actions, noting coherence, monitoring negative and monitoring positive as the dependent variables (Table 7). The number of principle statements was not entered into the analysis has no text student made any principle-based self-explanations. The only significant difference between the types of self-explanations was for the goal driven explanations ($F(1,18) = 6.36$, $MSE = 8.46$, $p=0.021$).

These analyses show that students in the diagrams condition produced significantly more self-explanations than students in the text condition. This was due primarily to differences in the number of goal driven explanations. There were no differences in the number of monitoring statements.

Are their greater benefits for self-explaining depending upon format on materials?

Pearson Correlation Coefficients were calculated for the number of self-explanations produced by the students and their scores on the pre-test questions (blood path and multiple choice, scored out of 19) and post-test questions (blood path, multiple choice, implicit and inference questions, scored out of 41) for each condition separately.

Table 8

Correlations between Mean Number of Self-Explanations and Pre-test Total, Post-test total by Format

	Pre-test total	Post-test total
Diagrams (n = 10)	.215	.74*
Text (n=10)	-.49	-.55

Note. * = p<0.05, (two tailed test of significance)

As can be seen from Table 8, there was a single significant effect. Students who produced more self-explanations in the diagram conditions scored also scored higher on the post-test.

Discussion

Do students learn more they study diagrams or text?

Participants in the study who were given information about the cardio-vascular system in diagrammatic formats learnt more than those given equivalent information textually.

The first task (given at both pre and post-test) required subjects to draw the path of blood flow on an outline of a human body. At post-test, students presented with diagrams included almost four more correct concepts than they had a pre-test compared to text students who only included one extra correct concept. For example, more than half of the students in the diagram condition showed the pulmonary and systemic circulation in their diagrams but only one student did in the text condition. However, it could be argued that this task is easier for diagrams students. They had been presented with blood flow information in diagrammatic format whereas text students will have had to infer the relation between the textual description of blood flow that they had been given and the body outline. To claim that diagrams differentially aid learning, it is important to examine performance on the other tasks.

The multi-choice questions were presented in the form of five text and five graphical questions counter-balanced on the pre and post-test. Hence, there is no simple compatibility of format advantage for either condition. Again the diagrams condition was found to significantly outperform the text condition. At post-test, 80% of the answers diagram student gave were correct compared to 56% of the answers of text students. Moreover, the implicit and knowledge inference questions were presented only at post-test were asked and answered in textual form. It might therefore be argued that this creates an advantage for text condition learners. However, the diagram students performed better than the text condition student, particularly on the harder knowledge inference questions (a mean of 78.3% in the diagrams compared to 46.6% in the text).

There are a number of reasons why pictures and diagrams might facilitate learning in this domain. The differences between the diagrams and text in this experiment are proposed to be chiefly explained by computational offloading and graphical constraining. For example, when picturing the structure of the heart, blood vessels and blood path throughout the body it might be expected that as diagrammatic representations explicitly preserve information about topological and geometric relations among the components then they would facilitate understanding of these concepts (Larkin & Simon 1987). Diagrams seemed to be particularly beneficial for the knowledge inference questions, which tested students' abilities to construct correct mental models. In fact, over 50% of the variance in scores is explained by format ($\eta^2 = 0.535$). This finding is line with that proposed by other researchers who suggest that pictures should facilitate construction of mental models (*e.g.* Mayer, 1993; Schnotz, 2002). In addition, the results of this study points to a new reason why diagrams may benefit learning; that they can promote the self-explanation effect.

Do students generate more self-explanations when they study diagrams or text?

Students in the diagram condition generated significantly more self-explanations than students in the text condition. This was not because they studied longer or spoke more, as diagram students spend significantly less time learning and uttered significantly less words. It would appear that diagrams can provoke students to self-explain more which in turns leads to both more effective and efficient learning compared to equivalent text.

There are multiple differences between text and diagrams and these differences exist at many levels (*e.g.* cognitive, semantic and affective). It corresponding likely that there are a multiple reasons why studying diagrams may lead learners to generate more self-explanations. Furthermore, it quite feasible that learners' behaviour will be influenced by several factors simultaneously.

Firstly, diagrams can reduce memory load and cognitive effort by providing a form of computational off-loading. Self-explaining is a challenging and effortful activity that many learners do not engage in spontaneously (*e.g.* Chi *et al,*1989; Renkl, 1997). It could be argued that by providing information in diagrammatic form, we freed the limited resources of learners to engage in meaning-making activities. Stenning and Oberlander (1995) have proposed that diagrams limit abstract and aid processibilty by restricting the learners' interpretation of the situation. For example, the sentence "Blood from the left ventricle flows through the left semilunar valve, into the aorta, and then throughout the body" does not make explicit the relative size and exact positions of these features whereas the diagram does. If learners in the text condition are struggling to infer these features, then they may not have sufficient resources available to self-explain. Furthermore, the working memory model (*e.g.* Baddeley & Hitch, 1974, Baddeley, 2000) would suggest that self-explanations and written text are processed by the phonological loop component of working memory whereas the diagrams are processed by the visual spatial scratch pad. A number of researchers propose that learning can be made more effective by presenting information in two modalities so that processing is distributed over multiple systems (*e.g.* Mayer & Moreno, 2002; Mousavi, Low, &

Sweller, 1995). Thus, self-explanations processed by the phonological loop and diagrams processed by the visual-spatial sketchpad may maximize efficiency.

Secondly, diagrams can make certain topological and geometrical information explicit (*e.g.* Larkin & Simon, 1987). This seemed to encourage learners to give extended explanations that link part of the diagram together focusing on the causes of such linking. For example, "*blood flowing in here to the heart has then to be pumped to the lungs to be oxygenated*".

Diagrams also seemed to encourage learners to impose causes for phenomena by encouraging a more global perspective across multiple diagrams. For example, students studying the diagram depicting the structure of blood vessels generated the following self-explanation: *"…an artery seems to be more muscular than a vein, because it carries blood with higher pressure…it has to carry it all the way to all the parts of the body….*" The reasons for this are not entirely clear. One possibility is that diagram learners were encouraged to create mental images (the mind's eye hypothesis (*e.g.* Kosslyn, Pinker, Smith, & Shwartz, 1979; Kosslyn, 1994; Tabachneck-Schijf, Leonardo, & Simon, 1997)) which encouraged them to integrate new information into this picture. Another possibility relates to the specificity of graphical representations (*e.g.* Stenning & Oberlander, 1995). Consider the sentence "Blood from the right ventricle flows through the semilunar valve into the pulmonary artery and then to the lungs".. Nowhere in this sentence is information about whether the blood is oxygenated or not deoxygenated. This has to be inferred from information given in other sentences. Yet, in the equivalent diagram (using red and blue as keys for blood high in Oxygen and Carbon Dioxide) it is impossible not to see that pulmonary artery carries deoxygenated blood. This specificity of information seemed to encourage learners to create a context for currently presented information by imposing goals ("*blood flows through the pulmonary artery to the lungs to get oxygen"*). Of course, it is not impossible to add "deoxygenated" to the sentence above. However, this tends to lead to writing which feels overly complex. It may be possible to add more specific information to text, but it will tend to be easier with graphical representations.

There may also be affective reasons for the greater number of self-explanations in the diagrams condition. Students' self-reports indicated that they found the diagrams more interesting to learn with that the equivalent text. The use of colorful images, with different styles of graphics for different sections of the information was unsurprisingly considered more motivating than the rather dry text. Mayer (1993) suggests that when material is made more interesting, students pay more attention by selecting more information for active processing. This is consistent with our observation that diagram learners actively self-explained material that text students fairly passively paraphrased.

We also need to consider what it is about the textual representations that made learners less likely to self-explain. The text students spoke significantly more than diagrams students, generating around 32% more words. However, the vast majority of their statements were simple paraphrases of the text. This difference between conditions is not due to problems of coding as we coded explanations in the diagrams condition with reference to the text. Thus, a statement in the diagram condition was only coded as an explanation if it provided information not given in text condition. The explanation seems to rest partly on the students seeming to believe that the text was in some way more "complete". They tended to treat each sentence (or few sentences) as providing all the relevant information and did not reason about goals or wider context of the information. As an example, after the sentences "The septum divides the heart lengthwise into two sides. The right side pumps blood to the lungs, and the left side pumps blood to other parts of the body. Each side of the heart is divided into an upper and lower chamber.", a typical text condition paraphrase was "*The heart is divided in half by the septum*" which upon prompting by the experimenter was only further extended to *"because it has different chambers and they need to be divided*". Whereas in the diagrams condition, a typical explanation is "*The septum is like a wall because you need to separate the oxygenated from the deoxygenated blood*". In addition to reliance on paraphrases, the other noticeable behaviour of the some learners in the text condition was the development on metaphors and analogies to describe the text. For example, *"…blood travels like a river!…so the arteries are the river, and the smaller vessels called arterioles are the tributaries…and then we have even more tributaries…"* and *"…Actually this is like a pyramid…we have a top-down system…capillaries are third…"* These metaphors often seemed to have perceptual characteristics. It would appear that in the absence of images to look at, at least some students in the text condition were creating mental images of the text. However, this style of self-explaining did not correlate positively with learning outcomes.

Is self-explanation more beneficial for learning from diagrams or text?

Overall, there was a significant positive correlation between the number of self-explanations and the post-tests scores. However, when examining this more closely by format, there was a single significant positive correlation between self-explaining and learning outcomes and that was for the diagrams condition. No significant correlation was found between the self-explanations produced by the text condition with their total post-test score. Therefore it appears that self-explaining is more beneficial for the students who studied diagrams of the human circulatory system, than for students in the text condition. Furthermore, Renkl (1997) showed that learners who focused their explanations either around principles and goals or who anticipated steps in the solution of probability problems were more frequently successful learners than those whose explanations were elaborations of the situation. The only significant difference in the type of self-explanations according to condition was for goal-driven explanations where diagrams students generated significantly more than the students in the text condition.

This finding supports the predictions of Aleven & Koedinger (2002) who proposed that self-explanations are particularly beneficial when they allow learners to integrate textual and graphical modes of expression. It also supports Cox's views that diagrams can provide salient feedback to encourage learners to give self-explanations and that translating between modalities will be beneficial in constructing a deeper understanding of the situation. It does not appear to support Wilkins's fear that diagrams will inhibit the benefits of self-explaining by encouraging incorrect explanations based upon superficial understanding of the diagrams. In this case, the diagrams were primarily pictorial in nature with simpler format and operators than the more complex diagrams in her mechanics situations. Learner also reasoned with presented representations rather than constructing their own representations from text. Thus, the results of this study do not contradict her hypothesis but illustrate the likely scope of its effect.

Conclusion

This study has shown that diagrams can promote the self-explanation effect. Students generated significantly more explanations and particularly goal-directed explanations when learning with diagrams rather than text. It also found that giving self-explanations when reasoning with diagrams is particularly beneficial for learning. Consequently, this result of this research adds more evidence to the growing body of research that shows that self-explaining is an effective metacognitive strategy and supplies a further reason why graphical representations can often be beneficial for learning. Furthermore, it may well be the case that as many of the preceding experiments involved both text and diagrams, that some of the reported facilitatory effects of self-explaining are due to the presence of diagrams in the worked out examples.

The current study was not designed to explore what features of diagrams can promote the self-explanation effect. The content of the self-explanations given by the students' implies they were sensitive to many different features of the representations. This is unsurprising as previous theoretical analysis and empirical research confirms that there are multiple differences between text and diagrams that can influence learning in many ways. One issue that remains to be explored is whether the effect is due to the way that diagrams promote verbal explanations or whether it rests on the interrelation between different forms of representation. For example, if students given text are encouraged to sketch explanatory pictures as a form of self-explanation will the same benefits accrue? Consequently, future research will be needed to explore if this effect is best considered as a diagram effect or a multi-representational one.

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