Concept mapping in problem based learning: a cautionary tale

Alex H. Johnstone and Kevin H. Otis

Centre for Science Education, University of Glasgow, Glasgow G12 8QQ, UK
e-mail: alexjo@btinternet.com

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Abstract: Problem Based Learning (PBL) and Concept Mapping (CM) have parallel purposes, both based on a constructivist view of learning. In a Faculty of Medicine, PBL and CM have been applied together as the main learning modes. This provided an opportunity to test several hypotheses about the interaction of CM and PBL. Among them were: (i) Students using CMs for their study and revision would perform better on their assessment tasks, than those who did not. This was supported, but not strongly. (ii) Students with 'good' maps would do better than those with 'poor' maps. This was not supported. Many students with apparently 'poor' maps treated them as a sufficient set of keys to unlock very large databases and these students did well. Other students with 'poor' maps confessed to having a tenuous grip on their work and this accounted for the quality of their maps. This raises problems about using maps for assessment purposes. It may be that maps should be treated as very personal learning tools for the writer's eyes only, analogous to a personal diary which could be easily misunderstood by a reader. [*Chem. Educ. Res. Pract.,* 2006, **7** (2), 84-95]

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Introduction

One important strand in the research at the Centre for Science Education has been to use an Information Processing Model to explore how students lay down information in Long Term Memory in a readily retrievable and useable form. Problem Based Learning is one method used to facilitate this.

The term Problem Based Learning (PBL) has recently been appearing in Science Education circles, in conferences and in the literature (Overton,, 2001; Belt et al., 2002). Even in casual conversation the title PBL is being applied to what used to be called tutorials, problem solving workshops and group exercises, and indeed they all involve some measure of PBL. Exercises in chemistry designed to promote discussion and group problem solving have been around for a long time (Percival, 1976, Johnstone, 1982, Wood, 1993, Schwartz et al., 1994). These have tended to be addenda to a more conventional mode of teaching through lectures.

However, the use of PBL as the main medium for learning in a discipline, or cluster of cognate disciplines, has been addressed by some of our medical colleagues. This is not a new phenomenon and medical schools across the world have embraced PBL as their medium for facilitating undergraduate learning (Barrows and Tamblyn, 1980; Schmidt, 1983; Barrows, 1986; General Medical Council, 1993).

The substance of this paper arises from experiences with PBL in the medical school in the University of Glasgow. Each university has its own version of PBL, but the common factors are to facilitate students' self-learning (as opposed to a didactic teaching and learning mode) and to encourage learning in context. In Glasgow the learning takes place through a series of 'real-life' scenarios in which the students learn the various strands of medicine (chemistry, biochemistry, anatomy, physiology, etc) in context. There is no formal teaching of these separate disciplines. Each topic, each concept, each discipline is met many times and from different angles and with increasing complexity. Gradually 'paper' scenarios give way to clinical incidents as the students progress. The overall aim is to facilitate integrated learning within concepts and between concepts. The earliest scenarios draw upon the students' pre-university knowledge and understanding providing points of attachment for new learning in Long Term Memory (LTM). As the knowledge and understanding base grows the frequent revisitation with more complex ideas allows a flexible network of ideas to be established. One of the basic tools in this learning process is the Concept Map. Students are encouraged to use the maps for three related purposes: to plan their work, to make explicit their own mental network and to prepare materials for later formal assessment. The maps are not themselves assessed, but they are aids for revision and inter-linking of knowledge. Concept mapping is associated with the work of Buzan (Buzan, 1974) and later with Novak and Gowin (Novak and Gowin, 1984). The suggested structure was to place a key concept (or node) in the middle of a page and surround this with closely related concepts (or nodes) linked by lines and some words to link them. The process was repeated with each of the new nodes and so on until a 'picture' of the knowledge and understanding structure was revealed. Such maps have been used in a range of learning processes such as planning, study, note taking, revision, problem solving and even for assessment.

Problem Based Learning and Concept Mapping can be seen as complementary (Table 1).

Table 1. The complementary nature of concept mapping and problem based learning.

	Concept Mapping	Problem Based Learning
Activate prior knowledge	Concept maps offer a method of visualising prior knowledge in the form of broad concepts and attaching the specifics of new information.	PBL activates prior knowledge by its application during the brainstorming session. This process also highlights gaps in knowledge.
Information supplied in the frame of a real problem	The use of a real life problem to form the first node of the map promotes the integration of academic and social data	PBL uses real life scenarios for two reasons: to tie new information to the likely cues for recall and to increase student interest by showing the relevance of new information to their work.
Elaboration on prior knowledge	Concept maps provide a structure on which new information may be assembled. The visualisation of this process allows its thoughtful integration into the students' expanding database.	The focus of PBL is the elaboration of prior knowledge. The students begin the process with what they already know. They then generate questions based on what they need to know to understand the scenario.

To complete this scene-setting introduction, we need to look at a typical week in the life of a PBL student.

Monday: PBL (2 hours). A group of eight students work with a facilitator. The first hour is devoted to discussion of the outcomes of the previous Thursday's tasks. The second hour is for the introduction and analysis of a new scenario and, during a 'brainstorming' session; students prepare a communal concept map, showing what they already know about the problems exposed in the scenario, and setting out what they need to know to tackle the problem fully.

Tuesday and **Wednesday:** Students work independently on the tasks arising from Monday, consulting books, computer data, research papers and any sources which might help them to meet the problem set out in the scenario. There are also laboratory sessions and workshops available, which are relevant to the problem.

Thursday: PBL (2 hours) as for Monday.

Friday and **weekend:** as for Tuesday and Wednesday.

Occasionally (not weekly) there is a lecture to integrate the work of the previous scenarios or to prepare the context for forthcoming scenarios. Almost half of the week is earmarked for private study, library work and report writing.

The facilitator (a member of staff drawn from medicine or science, trained to ask questions rather than provide answers) meets with the group of eight students. One student is appointed as chairperson and another as scribe. These 'posts' are regularly rotated round the group. Each student is presented with the scenario on about half a page of A4. This consists of a description of a situation, part of which might be familiar from previous work. The facilitator explains any unfamiliar terms and then the students, under the chairperson, have to decide on the main issues about which they need knowledge. The scribe records the ideas on a board in the form of a Concept Map to show linkages between the issues and to arrive at an agreed analysis of the problems. The facilitator can help with emphases on main concerns and deflect students from pursuing unprofitable lines. The students are then left with about six issues to be pursued. At the next PBL session students report back to communicate their findings, compare and resolve any conflicts and report on their information sources.

They are encouraged to produce their own Concept Map of the completed scenario and use it for further study, but this is an optional extra.

An evaluation study of the outcomes of the PBL in Glasgow was reported elsewhere (Mackenzie et al. 2003). This study ran alongside that of Mackenzie and her colleagues.

The Experiment

For administrative purposes the students in the first year PBL class were randomly assigned to one of three groups - A, B and C. Our experimental group (C) consisted of 82 students while the control was made up of groups A and B, totalling 160. The main thrust of the research was to observe students at work in a PBL situation in which they were encouraged to use concept mapping as a learning tool (Group C), but as this proceeded, several underlying behaviours appeared which will form the basis of this paper.

The initial research hypotheses were:

(i) Students who individually used concept mapping for study, planning and revision would have, on average, better scores in the battery of conventional assessment tests than those who used only the group concept map arising from each scenario.

(ii) As student knowledge and understanding increased, the maps for successive scenarios would contain more nodes and the inter-linkages would increase in number.

(iii) Students with the fullest (most complete) maps would be those who did best in their final assessment.

Group C students were given instruction in how to construct and use concept maps and they were strongly urged (but not obliged) to use them throughout their studies.

For each scenario, each student in group C was given four sheets stapled together. The top sheet contained the instructions for the experiment (Figure 1), while the other three blank sheets were non-carbon reproduction paper (NCR), a white, a yellow and a pink for ease of administration.

At the end of each scenario, before they had consulted books or any other resources, the students were asked to make a map of their present understanding of the scenario. This copied through all three sheets. The bottom pink sheet was detached, placed in an envelope and returned to the researchers.

Figure 1. Instructions for the conduct of the experiment to yield concept maps for each scenario

When you have finished answering your questions, put away your notes and books and follow these instructions.

- Turn the paper to landscape position and put your name and number in the top right hand corner.
- Reread the scenario.
- Use the name of the 'patient' as the central node.
- Expand the central node in concept map fashion.
- Expansion should be done one level at a time.
- Use all your previous knowledge (from primary school to last week) to explain the scenario.
- Try to limit the concept nodes to a couple of words and/or symbols; but this is your map, and so represent the ideas as you choose. If a list or a graph appeals to you, use it.
- When your map is complete, tear off the bottom pink page and return it in the envelope provided.

Now use your notes and books to make any additions or corrections to your map.

- When you have finished, tear off the bottom yellow page and return it in the envelope provided.

The remaining map on the white page should be kept and added to your notes for this scenario.

After the students had consulted literature and other sources, they were asked to elaborate or change their original map. This copied through both remaining sheets. The yellow sheet was detached and returned to the researchers. The students retained the white NCR sheet as part of their personal notes. They could elaborate this further as they progressed through other scenarios and noticed linkages between scenarios when the same concepts were revisited.

Results

1. Concept map returns

The total number of maps returned from ten scenarios was 546 pairs out of a possible 820 pairs. The commonest reason for the incomplete return was that some students used felt-tipped pens, which did not copy through to the lower sheets. Others used ball-point for some part of the maps and coloured felt-tipped pens for other parts. Students sent apologies, but did not make time to redraw the maps. Some students returned one sheet, but not the other, pleading forgetfulness. Only a very few students were completely uncooperative.

2. Analysis of maps

These were 'scored' by nodes, layers and linkages as suggested by Novak and Gowin (Novak and Gowin, 1984).

Nodes were concepts, ideas, sketches, graphs. The central node was the name of the main character in the scenario. The layer of nodes linked directly to the central node was layer 1. The next array of nodes linked directly to nodes in layer 1, were layer 2 nodes and so on. A 'rich' map would contain many nodes validly linked to nodes in inner layers.

There was a wide variation in the number of nodes appearing in maps based on the same scenario (table 2), and exemplified in the two maps shown in the Appendix. However the general pattern was that most maps had four level 1 nodes and each of these branched three times. Maps were four layers deep with specific detail around the edges. Nodes on the periphery had 2-3 times as many branches as interior nodes.

Table 2. Sample of Variation of the number of nodes for a given scenario

Student identifier	Scenario	Number of nodes
Student 202	4	83
Student 209	4	31
Student 234	4	46
Student 274	4	106
Student 278	4	79

However, there was a surprising finding. For about 25% of the students, the number of nodes in their maps was almost constant regardless of the changing complexity of the scenarios (table 3). The value of the 'constant' varied greatly between students. When students were interviewed near the end of the year, they were asked about this individual 'constant'. Typical replies were:

'I stopped when I had covered the topic.'

'I knew I couldn't learn everything, so I tried to be realistic and took on only what I thought I could remember.'

Table 3. Samples of nodes over eight scenarios of different complexity

Student	Sc1	Sc2	Sc 3	Sc 4	Sc 5	Sc 6	Sc 7	Sc 8
Student 210	47	44	46	47	46	–	44	45
Student 213	68	67	71	72	69	68	70	–
Student 234	45	45	46	45	43	44	46	44
Student 274	110	114	106	114	106	108	102	106
Student 279	59	58	58	59	61	60	59	58

As can be seen from table 3, the results from a random sample of this 25% of the students, based on eight very different scenarios, showed 'constants' varying from the mid-forties to over one hundred. If these 'constants' were a reflection of the students' coverage of the topic, then their perceptions of what was needed to comprehend the 'message' of each scenario differed considerably.

3. Map quality

Since concept maps are apparently gaining in popularity as potential assessment tools (Pendley et al., 1994, Regis et al., 1996, Edmundson, 2000; Stoddart et al., 2000, Nicoll et al., 2001) we took the opportunity to compare the analysis of the maps, using the scoring methods suggested by Novak and Gowin (Novak and Gowin, 1984) with the results of the normal battery of course assessments using multiple choice and extended questions. In fairness to these authors, they were not very enthusiastic about maps being used for assessment purposes and saw their function mainly as learning aids.

'Good' maps were characterised by many clear and validly linked nodes giving rise to clear layers, logically developed. 'Poor' maps were those with few nodes, weak linkages and indistinct layering.

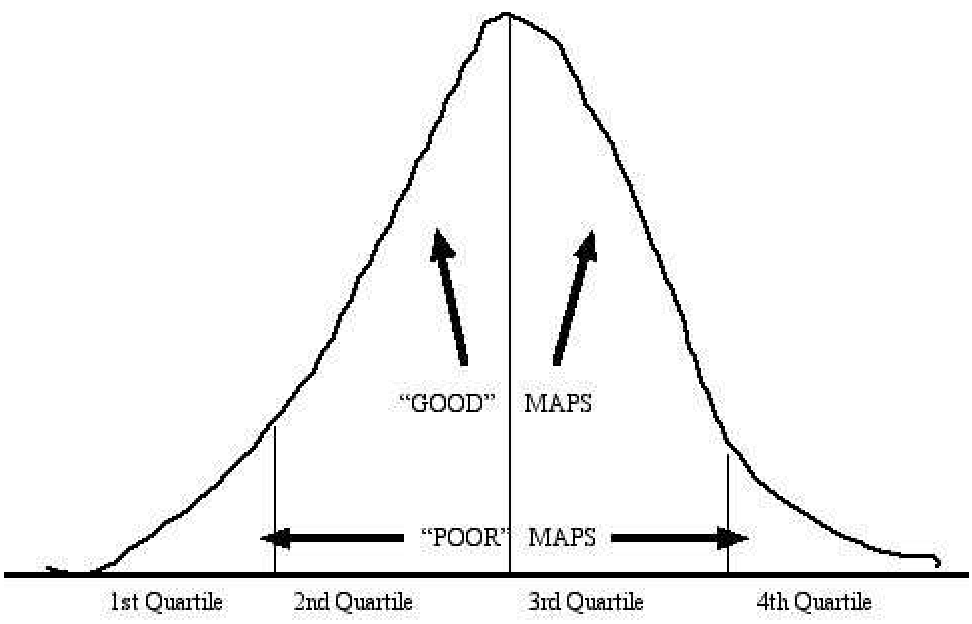
Such an analysis gave rise to three piles in our 546 maps. There were those which fell clearly into the two extremes set out above, but about one third came into intermediate positions such as those with many nodes, but set out in a chaotic fashion. It was difficult to do any rigorous correlation calculation between the map 'scores' and the normal assessment scores, but the following pattern emerged.

(i) Students, whose maps came into the 'good' and 'intermediate' categories, fell mainly into the middle two quartiles in the distribution of the normal assessment scores. This is not unexpected since the group represented 75% of the class and their distribution would approximate to 'normal'

(ii) However, students whose maps came into the 'poor' category, fell almost equally into the first and fourth quartiles of the normal assessment score distribution.

At first sight this seemed to be very strange, but interviews with twelve students in this category gave the explanation. Some of the students with 'poor' maps indicated that they did not have a good grasp of the scenarios and so their maps were sparse, ill-connected and unsatisfactory. Such students ended up in the lowest quartile. However, other students explained that they did not need a complex map, and that a simple, apparently 'poor' map was quite sufficient to act as a 'set of keys' to unlock their memory and reasoning store. Such students appeared in the highest quartile on the normal assessment battery of tests (Figure 2).

Figure 2. Distribution of maps across final exam results



Among the students who were interviewed were some whose maps were messy, ill-constructed, but node rich. On the scoring scheme, their maps fared badly and yet, when these students were asked to talk about the scenarios with the aid of their 'poor' maps, they could do so very cogently and well. What appeared to the observer to be a mess was a powerful tool for the constructor of the map.

These results have driven us to the conclusion that a map is a very personal thing, idiosyncratically constructed for the sole benefit of the individual student. It is likely to be misconstrued by an outsider; by anyone trying to assess what appears on paper.

The map is a memo; a set of keys; a collection of nodes which can spark off clusters of other nodes which need not be shown explicitly on paper. The best students may need only a skeleton map to unlock and activate a large body of knowledge and understanding. Does this imply that concept mapping is useless? On the contrary, it is a helpful learning tool which probably should not be pressed into service as an assessment tool.

When the results in the general course assessment were examined, group C students, who had used concept maps during the ten scenarios, scored (on average) about two percentage points higher than students in groups A and B who had acted as our control. (Table 4)

Table 4. Comparison of mean scores on conventional tests

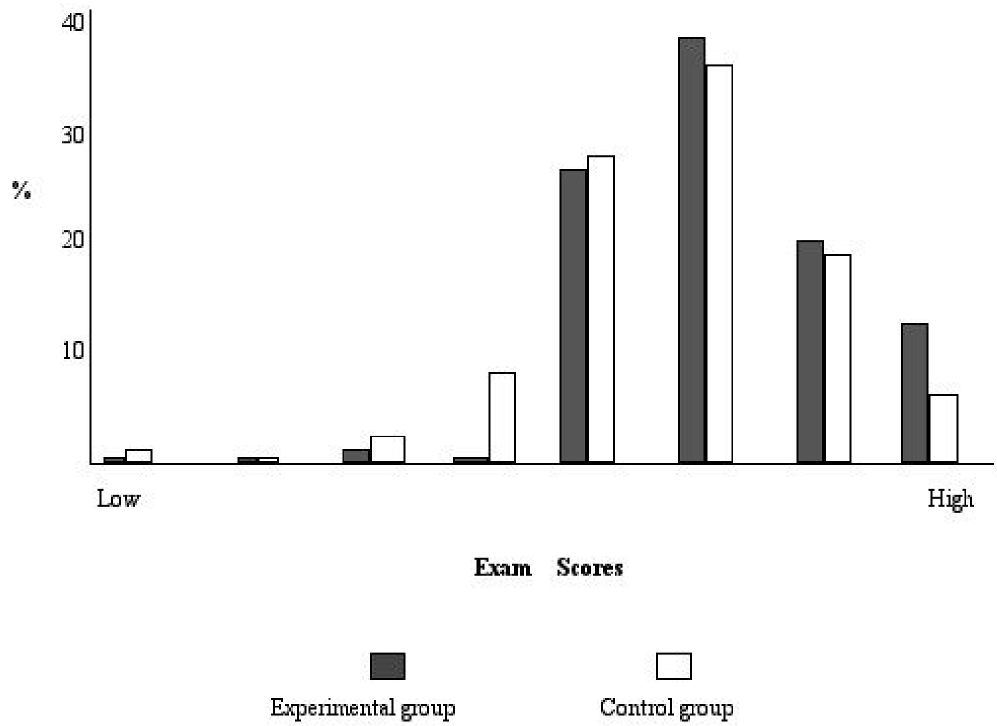
	N	Mean (%)	SD	SE
Control	160	66.3	5.5	0.4
Experimental	82	68.2	5.2	0.7

$t = 2.7$
Since $t > 2.0$, the means are significantly different at the 5% level

A final questionnaire administered to students in all three groups (90% return rate) showed that a significant proportion of the control group adopted concept mapping in their own studies of their own accord, having heard the recommendations from their colleagues in the experimental group.

It also turned out that some of the experimental group had given up mapping since they found it time consuming. The fact that the experimental and control groups were not wholly discrete would tend to reduce any differences in their mean scores, but the overall shift in the distribution in favour of the experimental group was significant at the 5% level, (student $t = 2.7$) (Figure 3).

Figure 3. Comparison of final exam results for experimental and control groups



Discussions and Conclusions

It is time to review our initial hypotheses.
(i) *Students who individually used concept mapping for planning, study and revision would have, on average, better scores in the battery of assessment tests than those who used only the group concept map arising from each scenario.*
This hypothesis has been supported by the results. The differences have been significant but not dramatic.
(ii)*As student knowledge and understanding increased, the maps for successively more complex scenarios would contain more nodes and inter-linkages.*
This was generally the case, but about one quarter of the students tended to produce maps with an almost constant number of nodes and linkages regardless of the nature of the scenarios.
(iii)*Students with the fullest (most complete) maps would be those who did best in their final assessment.*
This was not well borne out experimentally. Most students with 'good' maps fell into the quartiles immediately on either side of the mean, but were not well represented the highest and lowest quartiles.
Students with 'poor' maps were distributed, almost equally, between the lowest and highest quartiles.

Recommendations for Practice

1. From many studies (Pendley et al., 1994, Lee and Fensham, 1996, Herron, 1996, Sanger and Greenbowe, 1999) it has been shown that learning in the sciences has a tendency to be linear and boxed. Working from conventional notes and textbooks, topic A precedes

topic B followed by topic C. Each topic is in a sealed box with little or no interaction between them. Having taught bioinorganic chemistry, one of us (AHJ) has had student complaints about lectures in which thermodynamics, organic ligands and inorganic ions came together. The opening of the concept boxes and the mixing of their contents was upsetting and even painful for the students. Mother Nature seems to do this mixing with ease! Also students who could solve simultaneous equations in maths could not do so in physical chemistry.

Any device which aims to break down the linearity and compartmentalisation in our students' learning is to be encouraged. We believe that concept mapping has a contribution to make to this.

2. The skills of concept mapping have to be taught, but thereafter maps are the private, idiosyncratic aids and products of our students' learning.

3. It is very doubtful if concept maps should be used by a 'non-author' for assessment purposes. To be useful learning tools, concept maps may be unsuitable reading for another observer. They may be analogous to a personal diary with its abbreviations, allusions, selection of the important and memory jogging; rich in meaning for the writer, but easily misconstrued by a reader.

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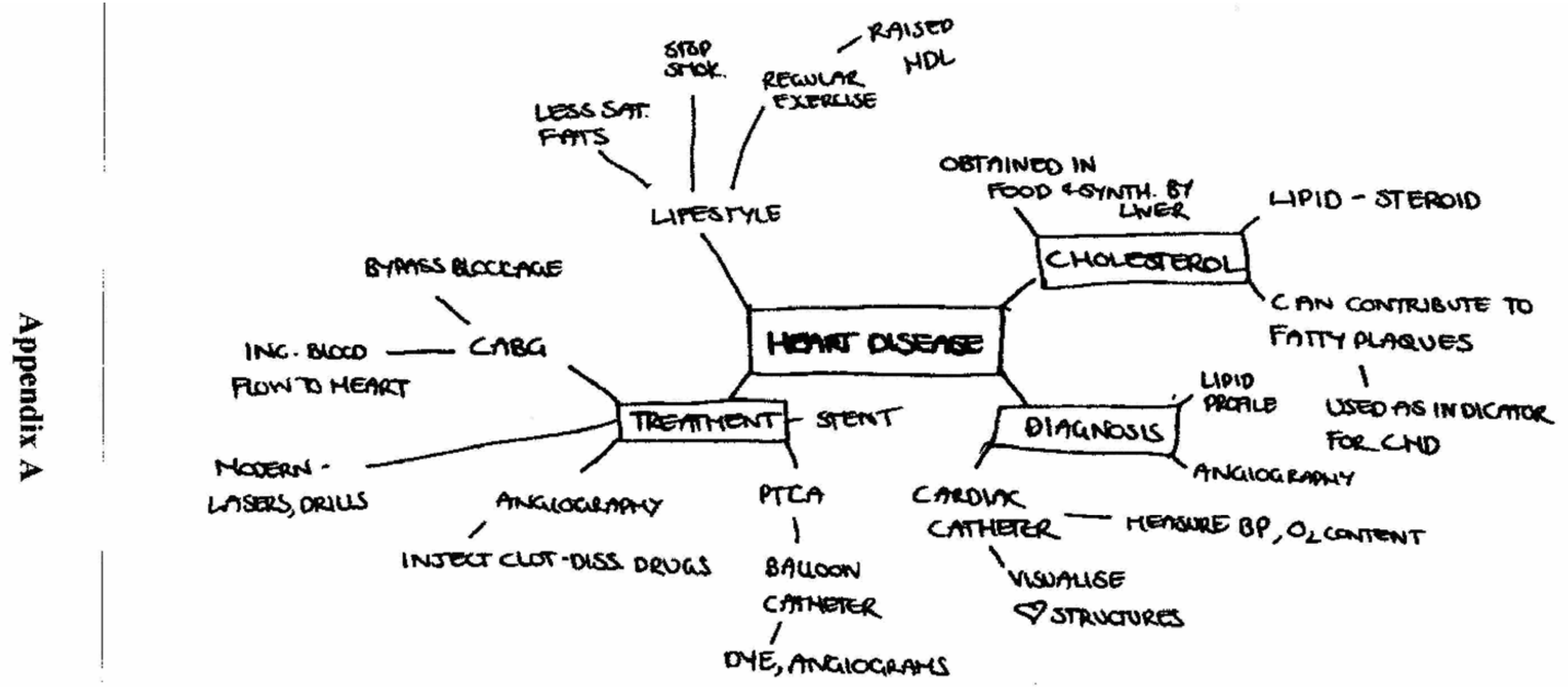
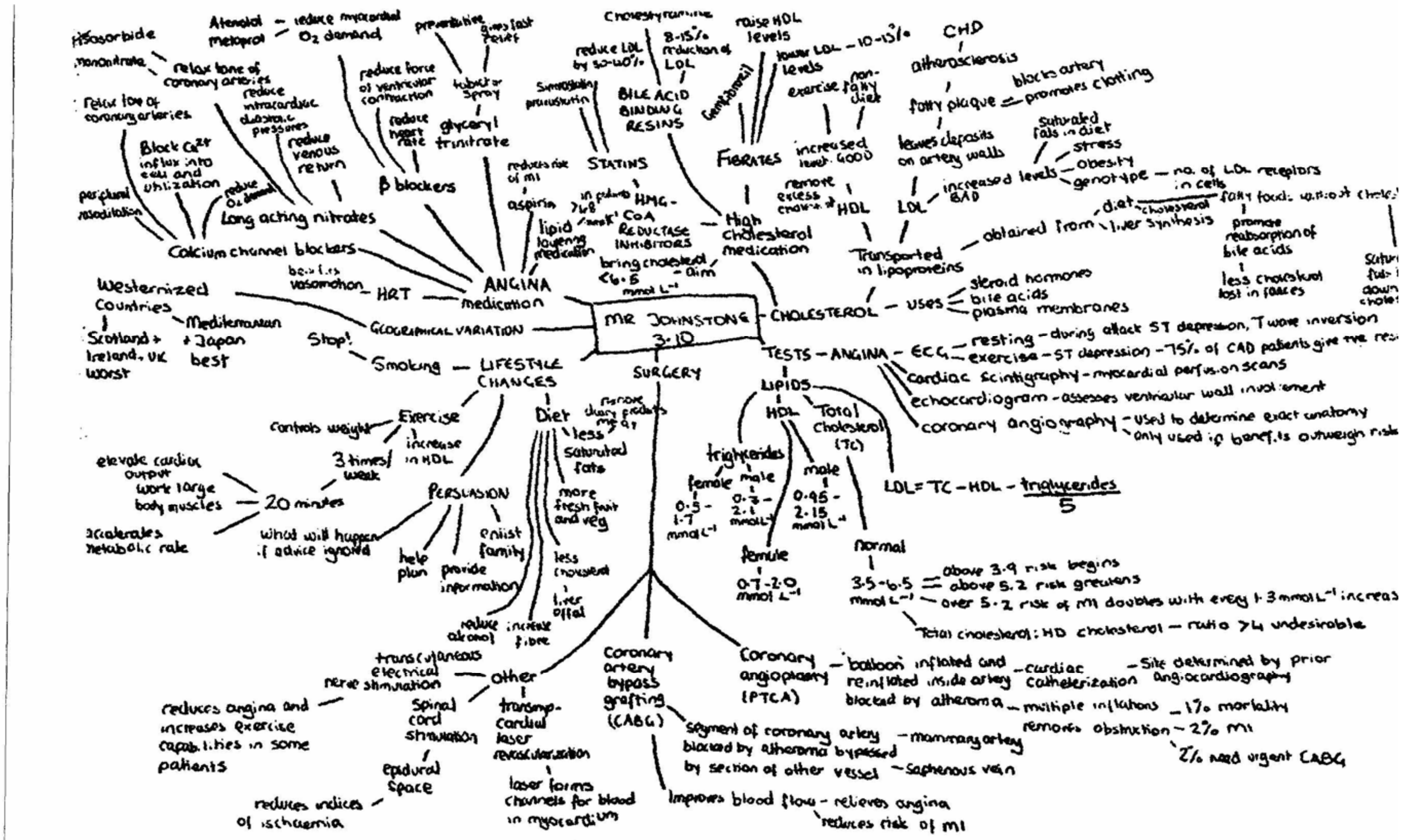
Appendixes

Appendix A



Appendix B


MR JOHNSTONE 3.10
ANGINA medication
Calcium channel blockers
Long acting nitrates
β blockers
glyceryl trinitrate
aspirin
STATINS
BILE ACID BINDING RESINS
FIBRATES
HMG-CoA REDUCTASE INHIBITORS
High cholesterol medication
CHOLESTEROL
Transported in lipoproteins
obtained from - diet, liver synthesis
uses - steroid hormones, bile acids, plasma membranes
CHD
atherosclerosis
fatty plaque - blocks artery, promotes clotting
leaves deposits on artery walls
LDL - increased levels BAD
HDL - increased levels GOOD
saturated fats in diet, stress, obesity, genotype - no. of LDL receptors in cells
Isosorbide mononitrate
relax tone of coronary arteries
Atenolol, Metoprol - reduce myocardial O2 demand
reduce force of ventricular contraction
reduce heart rate
Block Ca2+ influx into cells and utilization
peripheral vasodilation
reduce O2 demand
reduce venous return
preventative, gives fast relief
tablet or spray
reduces risk of MI
lipid lowering medication
bring cholesterol <6.5 mmol L-1 - aim
Cholestyramine
reduce LDL by 30-40%
8-15% reduction of LDL
raise HDL levels
lower LDL - 10-15%
exercise, non-fatty diet
Gemfibrozil
Simvastatin, pravastatin
HRT
GEOGRAPHICAL VARIATION
Westernized Countries
Scotland + Ireland, UK worst
Mediterranean + Japan best
LIFESTYLE CHANGES
Smoking - Stop!
Exercise
controls weight
increase in HDL
3 times/week
20 minutes
elevate cardiac output
work large body muscles
accelerates metabolic rate
Diet
less saturated fats
more fresh fruit and veg
less cholesterol
liver, offal
reduce alcohol
increase fibre
PERSUASION
what will happen if advice ignored
help plan
provide information
enlist family
TESTS - ANGINA - ECG
resting - during attack ST depression, T wave inversion
exercise - ST depression - 75% of CAD patients give +ve result
cardiac scintigraphy - myocardial perfusion scans
echocardiogram - assesses ventricular wall involvement
coronary angiography - used to determine exact anatomy, only used if benefits outweigh risk
LIPIDS
HDL
Total Cholesterol (TC)
triglycerides
female 0.5-1.7 mmol L-1
male 0.3-2.1 mmol L-1
male 0.95-2.15 mmol L-1
female 0.7-2.0 mmol L-1
LDL = TC - HDL - triglycerides/5
normal 3.5-6.5 mmol L-1
above 3.9 risk begins
above 5.2 risk greatens
over 5.2 risk of MI doubles with every 1.3 mmol L-1 increase
Total cholesterol : HD cholesterol - ratio >4 undesirable
SURGERY
other
transcutaneous electrical nerve stimulation
spinal cord stimulation
epidural space
reduces indices of ischaemia
reduces angina and increases exercise capabilities in some patients
transmyocardial laser revascularisation
laser forms channels for blood in myocardium
Coronary artery bypass grafting (CABG)
segment of coronary artery blocked by atheroma bypassed by section of other vessel
mammary artery
saphenous vein
improves blood flow - relieves angina, reduces risk of MI
Coronary angioplasty (PTCA)
balloon inflated and reinflated inside artery blocked by atheroma
cardiac catheterization
site determined by prior angiocardiography
multiple inflations
removes obstruction
1% mortality
2% MI
2% need urgent CABG