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A Systematic Approach to Solving Problems in Structure Analysis

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ABSTRAK

Suatu kajian kegagalan pelajar menyelesaikan masalah analisis struktur, walaupun dengan mempunyai pengetahuan yang perlu, dihuraikan. Strategi pengajaran yang diberi kepada pelajar untuk menolong mereka mendapat kemahiran dan keyakinan dalam penyelesaian masalah, dan penilaian terhadap strategi ini juga dibincangkan.

ABSTRACT

An investigation of students' unsuccessful attempts to solve problems in structure analysis, even though they possessed all the prerequisite knowledge, is described. The proposed teaching strategies given to these students to help them develop confidence and skills in problem-solving and the evaluation of these strategies are discussed.

INTRODUCTION

Structure analysis of organic molecules based on simple organic reactions and simple chemical tests form an important part of the first year Organic Chemistry course in the Bachelor of Science programme. Students at this level encounter many problems on this part of the course. Problems on structure analysis are usually amongst the lowest-scoring problems in tests. Experience shows that the transition from the knowledge of individual reactions to the application of these reactions in the identification of a given organic compound is far from being automatic. We often find that if a student is offered a series of consecutive transformations in a chart and is asked to identify the products or reagents and conditions at intermediate stages, he is often successful in doing so and is finally able to determine the structure of the given compound. However, if he is presented with a whole problem consisting of reactions and chemical tests and is asked to indentify the structure of a certain compound based on these reactions and tests, he stumbles and falters and occasionally comes out with only a partial solution, or no solution at all.

Several approaches have been recommended to overcome the difficulties encounted by students in problem solving of this type (Brandt *et al.*, 1979; Frazer, 1982). These have the nature of general strategies. Many students find general strategies of little help when they are immersed in a chemical problem or are at a 'dead-end'. The difficulties may be related to the average inherent mental capacities of the student, lack of training and exercise, and to a weak grasp of the basic elements of the course. Each of these can be blamed as the cause for the failure in the learning process.

One of the major differences between the novice and the expert is the greater amount of information the expert can handle (Larkin and Reinf, 1979). Through greater knowledge and experience, the expert sees a pattern ('chunks') in the given information. He is able to work with these chunks as if they are single items of information. On the other hand, the novice does not see the pattern and tries to cope with considerably more items of information. The question of processing chemical information by 'chunking' has been discussed by Jonhstone (1980) and Johnstone and Kellett (1980).

Whilst it is not possible to solve a problem if the problem solver does not have all the constituent knowledge and skills, a study by Frazer and Sleet (1984) of students' attempts to solve chemical problems revealed that possession of all the prerequisite skills was not necessarily sufficient to enable a student to solve a problem. It is important therefore to provide guidelines or strategies for students to assist them to develop a plan to solve problems. These guidelines should reduce the load on the problem solver's working memory by helping him to focus on the key information stated in the problem.

The aim of the study described in this paper was to identify students who had all the knowledge required to solve a given problem, and to ascertain why some of these students still could not solve the complete problem. Procedures for teaching such kind of problem solving were also investigated.

MATERIALS AND METHODS

Description of the Problem

Two problems were used in this investigation. The problems and the corresponding network showing the steps involved in reaching the solution are shown in *Figures 1* and *2*. The network was obtained by combining items of information. Three sources of information are normally available: information stated in the problem, information from memory, and information by reasoning. The complete details of developing problem solving networks are described by Ashmore *et al.*, (1979).

To find out whether or not a student could solve all the steps, each problem was broken down into a series or sub-problems. A sub-problem is defined as any problem which tests the ability to derive an item of information by reasoning with the information immediately preceding that item in the network. All the sub-problems used in this study are shown in Tables 1 and 2.

Every sub-problem was shown to the lecturers concerned to ensure that their students possessed all the knowledge and skills required to solve the main problem and its sub-problems, and that no terminology or words would be unfamiliar to them.

Test Procedures

A total of 94 students who were studying organic chemistry in the first year at two local (Malaysian) universities participated in this investigation. 94 students attempted problem 1 and its sub-problems and 43 attempted problem 2 and its sub-problems. The test procedures that were followed have been described fully by Frazer and Sleet (1984). The principal features of these procedures are as follows:

(i) The main problems and each of its sub-problems were presented one at a time. The main problem was presented first and then the sub-problems in the order they appeared in the tables.

(ii) Before attempting *any* problem the students read it for a short period of time and then answered the question written on a separate sheet: "How sure are you that you will be able to do this problem?" They responded to this question by circling a number from 1 to 5 where the numbers represented the following degrees of confidence:

- 5 Very sure I can do it
- 4 Fairly sure I can do it
- 3 Not sure whether I can or cannot do it
- 2 Fairly sure I cannot do it
- 1 Very sure I cannot do it.

(iii) After responding to this question the students attempted the problem. They were asked to show all their working on the problem sheet. At the bottom of each sheet, the students were asked to answer the question: "How sure are you that your answer is correct?" They responded to this question in a similar way to that described above by circling a number from 1 to 5 where the numbers represented the following degrees of confidence:

- 5 Very sure I am correct
- 4 Fairly sure I am correct
- 3 Not sure whether I am correct or not
- 2 Fairly sure I am incorrect
- 1 Very sure I am incorrect.

The time that should be allowed to solve each problem was estimated from experience with similar problems, from advice given by the lectures, and observations during pilot studies. From subsequent interviews with a large number of students, it was clear that shortage of time was not a signigicant factor in this study.

The students' written attempts were analysed using the network method (Ashmore, 1979). It was then possible to divide the students into four groups:

All attempts

- Problem correct
  - Test items for required knowledge are all correct — GROUP A
  - Some test items for required knowledge are incorrect — GROUP B
- Problem incorrect
  - Test items for required knowledge are all correct — GROUP C
  - Some test items for required knowledge are incorrect — GROUP D

Students in group A were classified as the successful students and those in group C as the unsuccessful students. A few students were expected to be in group B. This was not surprising since the context of the main problem might prompt the students to recall the information whereas the sub-problems did not prompt them; most likely, the students were able to obtain the solution by guessing, or, assuming the missing required knowledge.

Interviews

In order to obtain a clear understanding of the successful students' ability and the successful students' inability to solve the main problem, ten of the succesful and twelve of the unsuccessful students were interviewed within about a week of their attempting the problems. Each interview was recorded on audiotape. During the interview the four questions shown in Table 3 were put to each student in the order in which they were listed in the table. After a student had responded to question 1, and also to question 4, he was shown a card on which ten words shown in Table 4 were listed. Each student was asked to choose a word that summed up his feelings at the point referred to in the question. The student was told that if there was not a word that was close enough to sum up his feelings, it was not necessary to choose one, and he could suggest an alternative word.

Teaching Problem-solving Strategies

The strategies or guidelines for solving problems in structure analysis used in this study were based on PAM (a Program of Actions and Methods) (Mettes, 1980) and those developed by the groups at the Unversities of East Anglia and Leuven Brandt *et al*, 1979). These are shown in Table 5. Having identified the unsuccesful students, about half the total number were taught these strategies and the other half were used as the control group. Both groups were retested using the same main problems (Problem 1 and Problem 2). The same set of procedures used in the first test (before the guidelines were given) were again followed: they were asked to indicate their responses to the confidence scale both after reading the problem and after solving it.

RESULTS AND DISCUSSION

The focus of the investigation was on students who could solve a complete set of sub-problems. There were 46 such students for Problem 1 (nearly 50% of the total) and 17 for Problem 2 (nearly 40% of the total). The following results and discussion refer to theses students only. They were classified as successful or unsuccessful problem-solvers according to whether or not they also solved the relevant main problem. The number of successful and unsuccessful students are recorded in Table 6.

The degree of confidence indicated by the successful and the unsuccessful students are shown in Table 7 and Table 8 respectively. For the main problem, the successful students were quite confident both during the reading time and after attempting the problem. The unsuccessful students, however, were not as confident during the reading time whether or not they could solve the problem. After attempting the problem, they were less confident about their answer than they were about their ability before attempting it. For each of the two problems, as shown in Table 8, the degree of confidence of the unsuccessful students after attempting the problem distinctly dropped. The X-test indicates that the drop from 'confident' (degree of confidence 5 and 4) to 'not confident' (degree of confidence 3, 2 and 1) for both problems were significant at the 5% level.

The results were parallel to the responses given during the interviews. A few students interviewed said that they felt fairly confident after reading the problem (Question 1) since they had seen similar problems before (Question 2). However, those unsuccesful students who expressed a degree of confidence immediately after reading the problem became uncertain when they tried to solve the problem on the problem sheet. The difference in proportion is shown in Table 9, and the X-test carried out shows that the difference is significant at the 5% level. Indeed, it was clear from the interviews that during the reading time the unsuccessful students did not have a clear picture in their minds about how they would solve the problem (Question 3). Furthermore, after the reading time, they could not correctly work out on the problem sheet the steps required to solve the problem. On the other hand, the successful students could see quite clearly during the reading time how they would approach the problem.

It is clear then from this study that there were students who lacked the ability to organize the steps necessary to solve the main problem even though they had the ability to solve the separate steps when each step was defined precisely for them in the set of sub-problems. Generally, these unsuccesful students were quite confident in solving each sub-problem. There is therefore no doubt that a student's confidence in solving a sub-problem is a reflection of the fact that in a sub-problem the student does not have to decide what to do with the information since it is closely stated how it should be used. The load on a student's working memory is greater when the sub-problem has to be extracted from a main problem than when it is identified for him.

The findings reported here are similar to those reported by Frazer and Sleet (1984) in their investigation of students' attempts to solve problems in inorganic chemistry. Both studies confirm that for a significant proportion of students, possession of all the prerequisite knowledge and skills is no guarantee that they will be able to solve the problem. It is important that guidelines be given to assist students to develop a plan to solve problems. This is indeed clearly shown by the results of the investigation. The students who were unsuccessful in the first test (before the guidelines were given) could successfully solve the main problems in the second test (after the guidelines were given). Their answers to the problems were spelled out very clearly and they were more confident of these answers. They also showed a higher degree of confidence in their answers after being taught the guidelines (Table 10). X-Test indicate the change from 'not confident' in the first test to 'confident' in the second test was statistically significant at the 5% level. As for the control group, there was no significant inprovement in the way the problems were being solved; but there were slight increases in the degrees of confidence in the second test. However, the increases were not significant and these could just be due to their familiarity with the questions.

CONCLUSION

Whilst the possession of all the prerequisite knowledge and skills are no guarantee that the students will be able to solve a particular problem, it would be able to reduce the load on their working memory capacity if strategies were given as it would facilitate their attempts to obtain a 'clear picture' of the whole problem. This will then lead them to solving problems systematically. It is therefore important to provide the students with some guidelines in the early stages of problem solving. In addition, teachers need to give more opportunities for students to practise short problems corresponding to the sub-problems in this paper. In other words, in the earlystages, teachers should as far as possible present problems in which the amount of information the students have to handle at any one time is reasonable. Once they are successful in and familiar with such short problems they develop confidence. Later, with confidence and experience, the students will see patterns in data and as a result will be able to handle more and more information.

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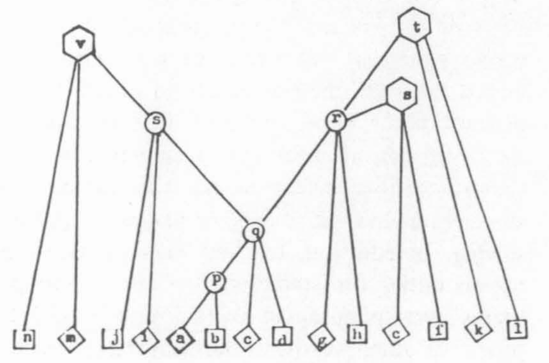
APPENDIX

Fig. 1 : Problem 1

Three compounds A, B and C are isomers with the molecular formula C_5H_8. All three compounds rapidly decolorize bromine in carbon tetrachloride and give positive tests with Baeyer's reagent (cold dilute solution of potassium permanganate).

Compounds A and B absorb two moles of hydrogen to yield n-pentane when heated with excess hydrogen in the presence of a platinum catalyst. Under these same conditions, compound C absorbs only one mole of hydrogen and gives a product with the formula C_5H_{10}.

When treated with ammoniacal silver nitrate, compound A gives a precipitate but compounds B and C do not. Oxidative cleavage of B with hot basic $KMnO_4$ gives, after acidification, acetic acid and propionic acid, and C gives $HOOCCH_2CH_2CH_2COOH$. Write down the possible structures for A, B and C.



Network for Problem 1

Information Stated in the Problem

(a) Three compounds A, B and C are with the molecular formula C_5H_8.

(c) All three compounds rapidly decolorize bromine in carbon tetrachloride and give positive tests with Baeyer's reagent.

(e) Compound A gives a precipitate when treated with ammoniacal silver nitrate but compounds B and C do not.

(g) Compounds A and B both yield n-pentane (C_5H_{12}) when treated with excess hydrogen in the presence of platinum as catalyst.

(i) Compound C absorbs only one mole of hydrogen and gives, a product with the formula C_5H_{10}.

(k) Oxidative cleavage of B with hot basic $KMnO_4$ gives, after acidification, acetic acid and propionic acid.

(m) Oxidative cleavage of C with hot basic $KMnO_4$ gives after acidification, $HOOCCH_2CH_2CH_2COOH$.

Information from Memory

[b] A, B and C have the same molecular formula, but different structures and are unsaturated.

[d] There are typical reactions of unsaturated compounds.

[f] Terminal alkynes show this reaction

[h] Hydrogenation saturates A and B.

[j] C should give a saturated compound when hydrogenated.

[l] Cleavage occurs at the multiple bond.

[n] Cleavage occurs at the multiple bond.

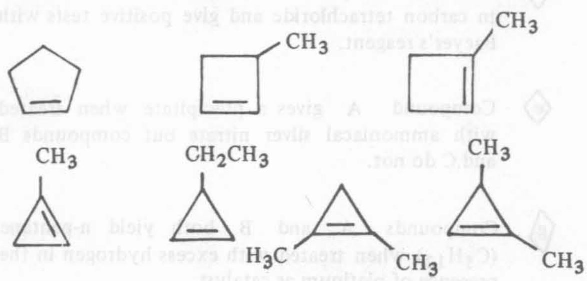
Information by Reasoning

(p) A, B, and C are 5-membered hydrocarbon. From the molecular formula, C_5H_8, the "unsaturation index" or degree of unsaturation is 2. Therefore, C_5H_8 contains one triple bond, or two double, bonds, or one ring with one double bond.

(q) The possible isomers are:

$CH_3C\equiv CCH_2CH_3$ $\quad$ $CH_2{=}CHCH{=}CHCH_3$

$CH\equiv C\,CH_2\,CH_2CH_3$ $\quad$ $CH_2{=}CHCH_2CH{=}CH_2$



(r) $C_5H_8 \xrightarrow[Pt]{2H_2} C_5H_{12}$

Since A and B absorb 2 moles of H_2, they have either one triple bond or two double bonds.

(s) Since B gives a precipitate with ammoniacal silver nitrate, A is a terminal alkyne, ie, 1-pentyne.

(t) Since B gives two compounds on cleavage, B has only one multiple bond, and it has to be a triple bond.

$$CH_3COOH + CH_3CH_2COOH \xrightarrow[\text{basic } KMnO_4]{\text{hot}} CH_3C\equiv CCH_2CH_3$$

(u) $C_5H_8 \xrightarrow[Pt]{H_2} C_5H_{10}$

Since only 1 mole of H_2 is absorbed to form a saturated compound, C must be an alkene and since C_5H_{10} is saturated, it must be a cycloalkane.

(v) Since oxidative cleavage of C gives only one compound, C must be a cycloalkene.

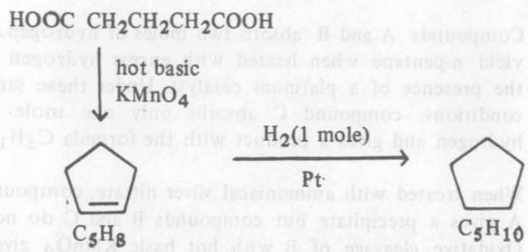


TABLE 1
Sub-problem for Problem 1

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n + m + u ⟶ v

Sub-problem 1

$A(C_6H_{10})$ is an alkene, H reacts with hot basic $KMnO_4$ to give $HOOCCH_2CH_2CH_2COOH$ after acidicication. What is the most likely structure of A?

---

i + j + q ⟶ u

Sub-problem 2

When treated with excess hydrogen in the presence of platinum as catalyst, a compound $B(C_8H_{14})$, absorbs only one mole of hydrogen to form cyclooctane (C_8H_{14}). What is the most likely structure of C? What is then the most likely structure of B?

---

k + 1 + r ⟶ t

Sub-problem 3

An alkyne $D(C_7H_{12})$ reacts with hot basic $KMnO_4$ to give propanoic and butanoic acids on acidification. What is the structure of D?

---

g + h + r ⟶ s

Sub-problem 4

An alkyne $E(C_6H_{10})$ gives a precipitate when treated with ammoniacal silver nitrate. What are the possible structures of E?

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e + f + q ⟶ r

Sub-problems 5

An unsaturated compound $F(C_4H_6)$ yields n-butane when treated with excess H in the presence of platinum as catalyst. What are the possible structures of F?

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c + d + p ⟶ q

Sub-problem 6

A compound G (C_5H_8) which has an "unsaturation index" of two rapidly decolorizes bromine in CCl_4 and gives a positive test with Baeyer's reagent. What are the possible isomers of G?

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a + b ⟶ p

Sub-problem 7

What is the "unsaturation index" of a compound H which has the molecular formula of C_9H_{16}? What does the "unsaturation index" of this compound tell you about its structure?

TABLE 2
Sub-problems for Problem 2

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s + t ⟶ u   Sub–Problem 1

On ozonolysis, A (C_5H_8) yields only one product B which does not contain the –CHO grouping. A forms an optically inactive diol when treated with cold aqueous alkaline solution of $KMnO_4$. What is the structure of A?

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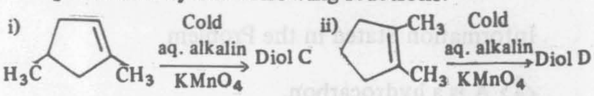
k + 1 ⟶ t   Sub-Problem 2

a) Write the structures of diols C and D produced by the following reactions:–



b) Which of the two diols (C or D) is optically inactive?

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i + j ⟶ s   Sub-problem 3

On ozonolysis, a cycloheksen E (C_8H_{14}) yields a compound which does not contain the -CHO grouping. What are the structure of E and F.

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p + q ⟶ r   Sub-problem 4

A cycloalkene $G(C_5H_8)$ gives $CH_3\overset{O}{\overset{\|}{C}}CH_2\overset{O}{\overset{\|}{C}}CH_3$ on ozonolysis. When hydrogenated using platinum as catalyst $G(C_5H_8)$ gives a cycloalkene $H(C_5H_{10})$. What are the structures of G and H?

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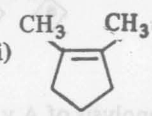
g + h ⟶ q   Sub-problem 5

a) Give the structures of the products obtained from the ozonolysis of the following compounds:

(i) $CH_3\underset{CH_3}{\underset{|}{C}} = \underset{CH_3}{\underset{|}{C}}CH_3$

(ii) 

b) Ozonolysis of a compound J gives a product which has the structure $CH_3\underset{O}{\underset{\|}{C}}(CH_2)_4\underset{O}{\underset{\|}{C}}CH_3$. What is the structure of J?

---

m + n ⟶ p   Sub-problem 6

A compound K reacts with 1 mole of H_2 using platinum as catalyst to give a saturated hydrocarbon $L(C_3H_6)$. What is the molecular formula of K? What are the structures of K and L?

---

d + e + f ⟶ n   Sub-problem 7

The empirical formula of a compound M is CH_2 and its molecular weight is 98. What is the molecular formula of M?

---

a + b + c ⟶ m   Sub-problem 8

One mole of a compound B reacts with only one mole of H_2 using platinum as catalyst to give a saturated hydrocarbon. What can you say about the carbon-carbon bond in N?

Fig. 2: Problem 2

One mole of hydrocarbon A reacts with one mole of H_2 in the presence of platinum as catalyst to give a saturated compound B. B has a molecular mass of 84 and a empirical formula of CH_2. Ozonolysis of A yields only one compound, C, which does not reduce Fehling's solution (ie, does not contain –CHO). The reaction of A with basic aqueous solution of $KMnO_4$ gives only one diol, D, which is optically inactive.

Work out the possible structures of A and show all the reactions involved in the form of a flow-chart.

Information Stated in the Problem

(a) A is a hydrocarbon.

(b) A reacts with 1 mole of H_2 to give B.

(d) B has an empirical formula of CH_2.

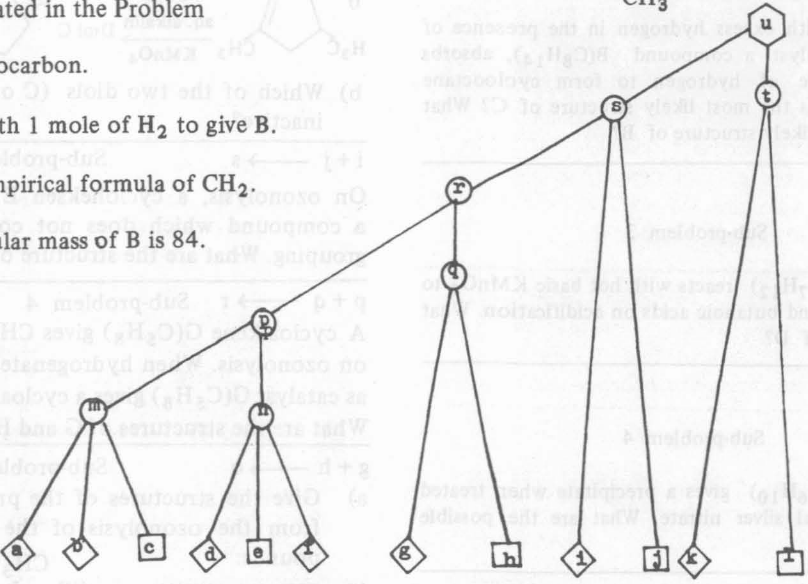
(e) The molecular mass of B is 84.

(n) n = 84/14 = 6. The molecular formula of B is C_6H_{12}.

(p) B (C_6H_{12}) is a cycloalkene.

(q) Since ozonolysis of A give only one product, A has either a cyclic structure or an open-chain structure sysmmetrical at the C=C bond.

(r) Since A does not contain H at C=C, the possible structures of A are



Network for Problem 2

(g) Ozonolysis of A yields only one product, C.

(i) C does not contain the -CHO grouping.

(k) A reacts with aqueous alkaline $KMnO_4$ to give diol D which is optically inactive.

Information from Memory

[c] A is an unsaturated hydrocarbon.

[f] The molecular formula of B is C_nH_{2n}

[h] Ozonolysis involves cleavage at the multiple bond.

[j] The absence of –CHO implies that there is no H at C=C in A.

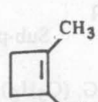
[l] The diol contains a plane of symmetry.

Information by Reasoning

(m) A contains only one double bond.

(t) Since diol D is symmetrical, A must be symmetrical at C=C.

(u) The structure of a is



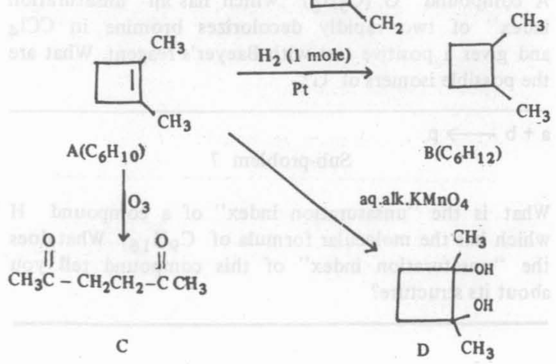


TABLE 3
Questions asked during interviews

1. What did you feel after you read this problem? (Student was shown a new sheet with the main problem? and the card which contain the list of words in Table 4).
2. Had you seen this problem before?
3. Before you started to work on the problem, did you feel that you had a clear picture in your mind about what the problem involved? Could you described that picture you had in your mind?
4. What did you feel at this point? (Student was shown his attempt at the main problem. The point referred to in the question was where the student had completed his working. Student was also shown the card with the list of words as in question 1).

TABLE 4
Words written on interview cards

Confident	Uncertain
Relieved	Tense
Pleased	Frustrated
Happy	Confused
Successful	Inadequate

TABLE 5
A Systematic approach to solving problems in structure analysis

1. Analysis of the problem:
   1. Set out the problem in the form of a schematic outline.
   2. Write down all the information given for each compound in the outline and any additional data from memory.

II Solving the problem.
   3. Calculate the degree of unsaturation of each compound and interpret this in term of possible combinations of rings and multiple bonds.
   4. Write down possible explanations for each step in the schematic outline.
   5. Work through the scheme, starting from the part where these is most complete information, eg, from the available structural formula.
   6. Write down the required structural formula formula and indicate the end solutions of the problem.
   7. If unsuccessful with the above steps, search for additional information or re-interpret the available data.

III. Checking for alternative solution
   8. Check for alternative solutions.
   9. Check that the proposed solution is chemically correct and fits all the information in the problem statement.

TABLE 6
Performances of students with a set of sub-problems correct

	Problem 1	Problem 2
Number of successful students (Students with main problem also correct	16	2
Number of unsuccessful students (Students with main problem incorrect)	30	15
Percentage with main problem incorrect	65%	88%

TABLE 7
Degree of confidence shown by successful students before and after solving problem

	Number of Students			
	Problem No. 1 (n=16)		Problem No. 2 (n=2)	
Degree of Confidence	Before	After	Before	After
5	2	6	0	1
4	8	8	1	1
3	6	2	1	0
2	0	0	0	0
1	0	0	0	0

TABLE 8
Degree of confidence shown by unsuccessful students before and after solving problem

	Number of Students			
	Problem No. 1 (n=30)		Problem No. 2 (n=15)	
Degree of Confidence	Before	After	Before	After
5	0	0	0	0
4	11	3	7	0
3	17	18	5	8
2	2	7	3	6
1	0	2	0	1

TABLE 9
Confidence shown by students after solving problem

	Number of Students			
	Problem No. 1 (n=46)		Problem No. 2 (n=17)	
	Confident[a]	Not Confident[b]	Confident[a]	Not Confident[b]
Successful Students	14	2	2	0
Unsuccessful Students	3	27	1	14

a 'confident' refers to degree of confidence 5 and 4

b 'not confident' refers to degree of confidence 3, 2 and 1

TABLE 10
Degree of confidence shown by unsuccessful students after teaching strategies

Degree of Confidence	Number of Students			
	Problem No. 1 (n=15)		Problem No. 2 (n=7)	
	Pre-test	Post-test	Pre-test	Post-test
5	0	7	0	3
4	2	6	0	3
3	9	2	4	1
2	3	0	3	0
1	1	0	0	0

TABLE 11
Degree of confidence shown by unsuccessful students (The Control Group)

Degree of Confidence	Number of Students			
	Problem No. 1 (n=15)		Problem No. 2 (n=8)	
	First Test	Second Test	First Test	Second Test
5	0	0	0	0
4	1	9	0	1
3	9	6	4	4
2	4	0	3	3
1	1	0	1	0