PROBLEM-SOLVING IN STEREOCHEMISTRYˇ

Mei-Hung Chiu
National Taiwan Normal University
Graduate Institute of Science Education
88, Sec 4 Ting-Chou Road
Taipei, Taiwan 11718

Hwa-Wen Fu
Duke University
North Carolina, USA

Paper presented at the annual meeting for the Australian Association for Research in Education (AARE), 22nd-25th November, 1993, Fremantle, West Australia.

ABSTRACT

This study focuses on understanding how students solve problems in stereochemistry (i.e., decide the isomer type of a compound). In particular, how students solve problems with different representations of moleculars, and the ideosyncratics of their problem-solving strategies. Subjects were individually monitored by the researcher using a thinking-aloud method. With this method subjects were given tasks and asked to describe howˇ they are solving the task. The data consist of a transcript of each problem-solving session and written work the subject produced. All the sessions were audiotaped and videotaped for later transcription and analysis. The finding suggests that on average, the successful students outperformed the non-successful students on all four types of questions (namely chemical formula (Type I), 2-D (Types II) & 3-D representations (Type III) and real molecular models (Type IV)). Surprisingly, the biggest difference between the successful students and non-successful students was on Type II which is included a cyclic chemical compound to increase the complexity of the problem situation. Even though this item was tested, we found that the successful students were able to transform a 2-D representation to multiple useful representations to solve the problem, whereas the non-successful students were unable to “visualize” the problem from different perspective. The smallest difference was on Type IV

which provided the students with concrete models for solving problems. This finding suggests that most students were beneficial from using 3-D models. We also found that the successful students were able to “see” the similarities between questions and applied their problem solving strategies back and forth, whereas the non-successful students considered each questions in isolation.
ˇ

Instrumentˇ

Four representations of moleculars were used to investigate students’ performance, namely, molecular formulas, 2-D and 3-D representations, and real molecular models. The test items are designed to test which problem representation is more useful and meaningful for students to solve and how students make use of the molecular kits to solve the problem. Samples of test items are presented below.

(1) molecular formula.

(2) Two-D representation.

Table 4. Time spent for each type of question by ability level.

Palatino(´#(build a model)... the two whites
represent a hydrogen. And this
"one is red may be chlorine that,
the grey would be bromine.
So, if I were to take a mirror
image of this, the mirror image
is going to be like this.... the red
is at the top and grey is at the
bottom ...you turn 180 degrees
down, OK, red is gone below and
grey has gone up... the two whites
of course make no difference .....

OBJECTIVES

In order to promote our understanding on how students solve problems with or without extended aid (i.e., molecular kits) in stereochemistry, we focus in this report on how successful students came to solve problems more effectively as opposed to non-successful students. The study was designed to answer the following question:

Which type(s) of representations of chemical compounds is (are) more helpful for students’ on problem solving?

In particular, we would like to investigate if there are differences between successful students' and non-successful students' mental models of problem representations and if there are differences between their problem solving strategies (both with and without the use of models).

Data analysisˇ

This study uses the method of analyzing and coding verbal data suggested by Chi (1993). Eight steps are listed below. As Chi points out, each step must correspond to the question being asked in the research:
1) reduce the data;
2) select a grain size to segment the verbal data;
3) determine the feature(s) to be used for the segmenting;
4) develop a taxonomy or some knid of formalism (e.g. network), to code the segments;
5) determine what evidence in the verbal data constitute a mapping to the formalism;
6) depict the coded data (sometimes optional);
7) seek pattern(s) in the coded formalism that reveal something about the strategy or the structure and content of knowledge;
8) interpret the pattern.

Based on this methodology, the researchers developed a scoring system to evaluate the students' performance and analyzed their problem spaces to untangle their mental representation and solution path for the problems.

THEORETICAL BACKGROUND

In the following sub-sections, we would like to draw relationship between molecular kits and mental models from some research findings.

Molecular kitsˇ

Molecular models are primarily used by teachers as manipulated visual-aids and lecture demonstrations. Ever since 1970, Smith found that there is a significant relationship between manipulation of concrete oriented models and the resulting cognitive performance. Talley (1973) pointed out that molecular kit had been utilized by the students as a device for assisting in critical thinking. He further surmised that the student has been able to transfer from the specific subject matter covered by the model to higher conceptualizations by enhancing his ability to visualize through the concrete manipulation of the models. Of particular importance in the study was the finding that the utilization of molecular models as an instrument to aid in

visualization of chemical concepts results in greater achievement in freshman level college chemistry. Zoller (1990) also pointed out that making models helped students learn chemistry and solved problems in stereochemistry.
Due to the manipulation of concrete models, the conversion of abstractions and observations into utilizable concepts and data should become easier for the students. ˇ

Mental modelsˇ

According to Viscuso and Spoehr (1986), some important characteristics of mental models have emerged from research in cognitive psychology. Mental models are, first, runnable. They allow the user to make mental simulations of situations and events, and make predictions about how changes in one part of a system will affect the other parts. Second, since the propagation of such effects throughout an entire system must be simulatable, a mental model contains topographical or connectedness information. Third, causality is inherent in a mental model since the propagation of change across the simulated system implies causal links. And fourth, because causal propagation makes it possible to make inferences about the functions of different parts of the system, a mental model thereby contains functional information. Although there are other terms for mental models, there is a consensus that the mental models represent a combination of some runnable objects with the characteristics discussed above.

Studies of the differences between experts and novices in this domains have examined two aspects of mental models. For instance, Chi, Feltovich, and Glaser (1981), have studies knowledge representation, and have found that not only do experts have moreˇdomain-specific information in their mental models than do novices, but that information is organized more conceptually. DeKleer (1985) and White and Frederiksen (1985) have argues that experts in such domains often make of qualitativeˇ rather than quantitative reasoning. Qualitative reasoning permits the expert to make causal inferences about a system without having to make complex, quantitative calculations. This is consistent with Larkin and Reif (1979)'s work in which they found the expert problem solver displayed two behaviors that novices did not : (1) the expert used methods based on underlying principles, and (2) a low-detail qualitative representation was constructed to explore potential difficulties with the solution.

Therefore, we try to examine how students' mental models influence their problem-solving processes and if there is any differences of the nature of mental models between high and low achievers.

METHOD

Subjectˇ

Eight subjects were recruited from the campus advertisement at a university in U.S. during the summer of 1991. They were four graduate and four undergraduate students. The background of graduate students were various in organic, inorganic chemistry, biochemistry, and medical field. The undergraduate students were in the Department of Chemistry. They all took the organic chemistry before.
(3) Three-D representation.
(4)ˇreal molecular models.

Proceduresˇ

A review flowchart and a model kit were provided for the subjects' use. There were two purposes to use the flowchart; one was for helping them recall the knowledge about the stereochemisty, and the other is to practice the technique of "thinking-aloud". Each subject was first asked to "read" and "elaborate" the flowchart so the researcher could provide feedback about how well he or she was "thinking aloud". Following the warm-up task, the subject was given 9 problems to solve. The length of the sessions ranged from 40 minutes to 90 minutes.

Subjects were individually monitored by the researcher using the think-aloud method. With this method subjects are given tasks and asked to describe how they are solving the task. The researcher stressed to the subject that she was not interested so much in the answer to the task but how the solution was arrived at. All the problem-solving sessions were tape-recorded and video-taped for later transcription and analysis. The data consist of a transcript of each session and written work the subject produced.

RESULTS AND DISCUSSIONS

This section demonstrates the usefulness of different representational systems utilized by both more and non-successful students while in solving problems in stereochemistry.

Students' performanceˇ
For all categories of questions, overall percentage of correct answers on this problem-solving test was 79.17% (See Table 1). The greatest correct percentage was on Type IV questions (87.50%) which real molecular models were provided . The least correct

percentage was in Type II questions (53.12%) which were included regular and cyclic compounds in 2-D representations. Due to a cyclic compound included, students tended to have difficulty to visualize how the spatial relationships among atoms. Therefore, it was a surprise to obtain the low performance on Type II. These suggest that the students were less capable to solve problems with the planar representation. However, given the concrete models, they were able to answer more questions correctly.

Table 1. Students' performance on four types of problems.
ˇ

Students were then characterized into two categories (successful and non-successful students) based on their performance on the problem-solving task. Overall the successful students were scored 96.88% of correct answers, whereas the non-successful students were only scored 61.46% of correct answer. No matter who are more or non-successful students or not, there were consistent results showing that the least correct percentage was

on Type II questions (See Table 2). Table 2 shows on average, the successful students outperformed the non-successful students in all four types of questions. The biggest difference between the successful and non-successful students was on Type II (56.25%) which requires the students to decide the characteristics of a compound from a planar representation. The biggest difference on their performance indicates that the successful students were able to transform a planar representation to a more useful representation for decision-making.ˇ

The smallest difference was on Type IV (25%). This finding suggests that most students were more or less beneficial from using a concrete 3-D model. One explanation is that it might reduce the students' cognitive load on examining the moleculars from a 2-D perspective. All the differences between the successful and non-successful students are at .05 significance level except for Type IV.

Table 2. Students' performance on four types of problems by ability.ˇ

Time spent for problem solvingˇ

Knowing students' performance on those questions, we might wonder how their time was spent on the task. Table 3 shows that average time was used for each question. On average, the students spent about 158.64 seconds (about 2 1/2 minutes) for

each question item. The time for each type of question is as follows: 188.19 seconds (about 3 minutes) for Type I, 271.46 seconds (about 4 1/2 minutes) for Type II, 168.44 seconds (about 2 minutes and 48 seconds) for Type III, and 107.92 seconds (about one minute and 47 seconds) for Type IV.
If we compare this result with students' performance on Table 1, we found that the students took longest time on Type II but their performance was the lowest. However, the students spent the shortest time on Type IV but their achievement was the highest. This might further confirm that the concrete models help students solving complicate chemical problems.

Table 3. The time spent on each type of question.

Table 4 represents that the successful students spent less time (119.1 seconds per question, less than 2 minutes) than the non-successful students (248.90 seconds per question, about 4 minutes) on the problem-solving process. The results were consist in all four types of questions. The successful students can quickly select the correct rules or strategies for solving the problems directly. However, the non-successful students spent more time to wail around the problems without attacking the main point. So the successful students spent less time but showed better performance. All the difference of time spent between the successful and non-successful students were at .05 significance level except for Type IV.

Figure 5: GB's problem solving strategy for problem 10.ˇ˜

REFERENCES

Chi, M. T. H. (1993). ˇAnalyzing verbal data to represent knowledge: A practical guideˇ, unpublished manuscript. Learning and Research Development Center, University of Pittsburgh.

Chi, M. T. H., Feltovich, P. J., & Glaser, R. (1981). Categorization and representation of physics problems by experts and novices. ˇCognitive Science, 5, 121-152.

DeKleer, J. (1985). How circuits work. In Bobrow, D. G. (Ed.). Qualitative reasoning about physical systems. Cambridge, MA, MIT Press.

Larkin, J. H. & Reif, F. (1979). Understanding and teaching problem-solving in physics. European Journal of Science Education, 1, 191-203.

Talley, L. H. (1973). The use of three-dimensional visualization as a moderator in the higher cognitive learning of concepts in college level chemistry, ˇJournal of Research in Science Teaching, 10, 263-369.

Viscuso, S. R. & Spoehr, K. T. (1986). ˇHow does a mental model facilitate comprehension of instructions?ˇ Paper presented at the annual meeting of the Psychonomic Society, New Orleans, LA, November.

White, B. Y., & Frederiksen, J. R. (1985). QUEST: Qualitative understanding of electrical system troubleshooting. ACM SIGART Newsletter, 93, 34-37.

Zoller, U. (1990). Students' misunderstanding and misconceptions in college freshman chemistry (General and Organic), ˇJournal of Research in Science Teaching, 27, 10, 1053-1065.

Figure 2: GB's problem solving strategy for problem 4.

Again, the other non-successful students used incorrect rules to solve problems and consistently used the inappropriate strategies throughout the entire process. For instance, GS generated the mirror images, B and C, of compound A, then compare if B and C are the same to judge the isomer type of the compound (Figures 3, 4 and 5). However, as we can see, GS did not recognize this problem and consistently miused her incorrect decision-making process.

Figure 3: GS's problem solving strategy for problem 3 .

Figure 4: GS used the same strategy for problem 4.ˇ

Individual differencesˇ

The successful and the non-successful students were observed with different approaches to solving problems. The followings are examples to show how the differences were found to characterize the discrepancies.
ˇ

Non-successful studentsˇ

GB considered Item 3 as a planar compound so she thought that B was the mirror image of A, after rotating 180 degrees one could get compound C which was the same as compound B (Figure 1). Therefore, that molecule was a geometrical isomerism. She applied the same rule to solve problem 4, since C was same as A

but no longer equal to B, so the molecule was an optical isomerism (Figure 2).

Figure 1: GB's problem solving strategy for problem 3.

Finally, the non-successful students were less capable to reduce the degree of complexity of a complicate problem to a simple situation. For instance, GB represented the chemical compound of problem 1 as shown in Figure 6 which is different from what the successful students have (This will be discussed later.)

Figure 6: GB's problem solving strategy for problems 1.
ˇ

Successful studentsˇ

We found that the successful students tended to use more sophisticated skills and more principle-oriented strategies to solve problems. For instance, GB, a successful student, was able to use an internal plane of symmetry to judge a molecular's category in stereochemistry (i.e., geometrical or stereo isomerism) rather than just to perceive it from a 2-D perspective (Figures 7 and 8).

Figure 7: UD's problem solving strategy for problem 3.

Figure 8: UD's problem solving strategy for problems 4.ˇ˜

Another successful student, GC, was able to transform a 2-D representation to a 3-D representation in order to facilitate her visualization of the compound in a spatial orientation (Figures 9 and 10). With this ability, therefore, she was able to solve the most complicate question, Item 4, which has to be recognized its trans and cis forms before identifying the isomer type of the compound.

Figure 9: GC's problem solving strategy for problem 3.ˇ˜

Figure 10: GC's problem solving strategy for problem 4.

Finally, the successful student tended to make the problem simpler in order to facilitate problem-solving (Figure 11). This is quite different from the non-successful student as shown in Figure 6.

Figure 11: UT's problem solving strategy for problems 1.

The findings suggest that the successful students were able to "visualize" the chemical compound in its spatial relationship and apply their knowledge in a more sophisticated manner. While the non-successful students considered the chemical compound in planar representation therefore it prevented them from using a meaningful and useful representation for achieving the task. We also found that the students' mental models we observed have the characteristics we discussed earlier, runnable and functional. However, these mental models are incorrect or incomplete.

IMPLICATIONSˇ

There are three major findings: first, the successful students use multiple types of representations during problem solving processes, whereas the non-successful students consistently apply incorrect and incomplete strategies to problem situations; second, the successful students could "see" relationships between 2-D and 3-D representations, while the non-successful students were unable to "visualize" atoms' spatial relationship from a planar representation; third, the non-successful students was rigid on using their incorrect strategies and not to notice its conflict with the principles. However, they changed their answers when using the molecular models. This might suggest that school teachers should be encouraged to use molecular model kits in classroom teaching. Also, students should receive more training on using concrete models at the beginning of learning stereochemistry and then move to abstract level of thinking. Further analyses is under the research's agenda.

Data analysisˇ

This study uses the method of analyzing and coding verbal data suggested by Chi (1993). Eight steps are listed below. As Chi points out, each step must correspond to the question being asked in the research:

1) reduce the data;

2) select a grain size to segment the verbal data;
3) determine the feature(s) to be used for the segmenting;
4) develop a taxonomy or some kind of formalism (e.g. network), to code the segments;
5) determine what evidence in the verbal data constitute a mapping to the formalism;
6) depict the coded data (sometimes optional);
7) seek pattern(s) in the coded formalism that reveal something about the strategy or the structure and content of knowledge;
8) interpret the pattern.

Again, the other non-successful students used incorrect rules to solve problems and consistently used the inappropriate strategies throughout the entire process. For instance, GS generated the mirror images, B and C, of compound A, then compare if B and C are the same to judge the isomer type of the compound (Figures 3, 4 and 5). However, as we can see, GS did not recognize this problem and consistently misused her incorrect decision-making process.

Figure 3: GS's problem solving strategy for problem 3 .

Another successful student, GC, was able to transform a 2-D representation to a 3-D representation in order to facilitate her visualization of the compound in a spatial orientation (Figures 9 and 10). With this ability, therefore, she was able to solve the most complicate question, Item 4, which has to be recognized its trans- and cis- forms before identifying the isomer type of the compound.

Figure 9: GCs problem solving strategy for problem 3.