DOCUMENT RESUME

ED 396 914 SE 058 326

AUTHOR	Schmidt, Hans-Jurgen
TITLE	Students' Understanding of Molecular Structure and Properties of Organic Compounds.
PUB DATE	Apr 96
NOTE	14p.; Paper presented at the Annual Meeting of the National Association for Research in Science Teaching (St. Louis, MO, April, 1996).
PUB TYPE	Reports - Research/Technical (143) -- Speeches/Conference Papers (150)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Foreign Countries; High Schools; *High School Students; *Identification; *Misconceptions; *Organic Chemistry; *Science Tests; Scientific Concepts; Scientific Literacy

ABSTRACT

The purpose of this study was to investigate senior high school students' difficulties predicting the existence of hydrogen bridge bonds between organic molecules, investigate students' difficulties predicting the relative boiling points of simple organic compounds, and develop test questions that enable teachers to quickly get information about their students' difficulties. Fourteen free-response and multiple-choice questions were administered to 4,846 senior high school students. Students were not only asked to check an answer they regarded as correct, but also to give a reason for their choice. Results indicated that students' understanding of intermolecular forces is not precise enough. They did not consider all criteria that were necessary to predict whether molecules form hydrogen bonds. Students also had difficulties predicting the relative boiling points of unbranched and branched alkanes, mainly because they used the chain length as a criterion for their prediction. The study shows that systematic development of test items is crucial to avoid students using incorrect strategies to arrive at the correct answer. Tests that do not meet this criterion could produce misleading results. The multiple-choice items developed in this study can assist in the process of helping teachers use the findings of research in the classroom. (Author/MKR)

NARST National Association for Research in Science Teaching

1996 Annual Meeting
St. Louis, Missouri

Hans-Jürgen Schmidt

Dortmund University, Dept. of Chemistry
Otto Hahn Strasse, 44227 Dortmund
Germany

Students' understanding of molecular structure and properties of organic compounds

Students' understanding of molecular structure and properties of organic compounds

Abstract

The purpose of the study was to investigate senior high school students' difficulties predicting the existence of hydrogen bridge bonds between organic molecules, to investigate students' difficulties predicting the relative boiling points of simple organic compounds, and to develop test questions that enable teachers to quickly get information about their students' difficulties. Fourteen free-response and multiple-choice questions were administered to 4,846 senior high school students. Students were not only asked to tick the answer they regarded as correct but also to give reason for their choice. Results indicate that students' understanding of intermolecular forces is not precise enough. They do not consider all criteria that are necessary to predict whether molecules form hydrogen bonds. Students also have difficulties predicting the relative boiling points of unbranched and branched alkanes, mainly because they use the chain length as a criterion for their prediction. The study shows that systematic development of test items is crucial to avoid that students using incorrect strategies arrive at the correct answer. Tests that do not meet this criterion could produce misleading results. The experience gained in this study should be used in future empirical research. The multiple-choice items we developed can assist in the process of helping teachers use the findings of research in the classroom. The alternative of teachers interviewing their students is more time consuming and requires substantial training.

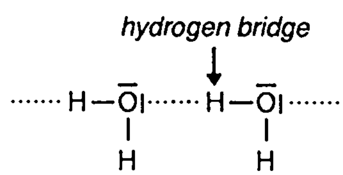
Introduction

In chemistry lessons we want students to learn fundamental ideas that enable them to make predictions. One of these ideas is the particulate model of matter. In this model, matter is composed of particles such as atoms, molecules, and ions. It is used to interpret phenomena like the changes in state of matter as opposed to chemical reactions.

In order to understand that different compounds - for example organic compounds - have different boiling points, the attractive forces between molecules have to be considered. These forces are *van der Waals* forces and hydrogen bridge bonds.

Molecules could be pictured as wrapped in a skin of electrons. This skin has a centre of charge which can temporarily shift from the centre of charge of the nuclei. In this way fluctuating dipoles within molecules arise. These cause weak intermolecular forces, the so called *van der Waals* forces. The magnitude of these forces increases with the size of the electron skin. For example, the surface of spherical molecules is smaller than that of straight molecules having the same molecular mass. Therefore, 2-methyl-propane, which has a branched carbon backbone, has a lower boiling point than its isomer butane, which contains a straight carbon chain.

Hydrogen bridge bonds hold molecules more rigidly than *van der Waals* forces. In a hydrogen bridge bond a hydrogen atom acts as a bridge linking a highly electronegative atom (e.g. F, O or N) to which it is bonded and a lone pair of electrons of the electronegative atom of another molecule. School textbooks mention hydrogen bridges between water molecules:



This explains why water has, compared to its molecular mass, such an abnormally high boiling point. Dimethyl ether has a lower boiling point than water even though it has a much higher molecular mass. The molecular masses of butane and 2-propanol are approximately equal. 2-propanol, however, has a higher boiling point because of hydrogen bonding.

Research into students' conceptual knowledge reveals a weak understanding of matter at the particulate level. A frequently observed misunderstanding is students' belief that particles get bigger as substances change from solid to liquid or gas (Gabel, Samuel & Hunn, 1987; Griffiths & Preston, 1992). Osborne and

Crosgrove (1983) report about students' idea that the bubbles in boiling water are made of hydrogen and oxygen. Novick and Nussbaum (1978) concluded from their research that conceiving interaction between particles is one of the most difficult aspects for students. It emerged from an investigation by Pereira and Pestana (1991) that only few students are able to produce accurate pictures and descriptions of hydrogen bonds.

It has to be further clarified why these areas of chemistry are particular difficult for students. Multiple-choice tests have been successfully used to obtain information about students' correct and incorrect strategies. It is of interest for teachers and researchers to know whether or not students have grasped a concept. In this context important criteria for multiple-choice questions are that

- incorrect strategies should not lead to the correct answer
- different common incorrect strategies should lead to different distractors.

Purpose of the study

The aims of the present study were

- to investigate students' difficulties predicting the existence of hydrogen bonds between organic molecules,
- to investigate students' difficulties predicting relative boiling points of simple organic compounds,
- to develop test questions that enable teachers to quickly get information about their students' difficulties. The questions have to meet the aforementioned criteria.

The latter aim emerged from the problem that empirical research is supposed to clarify how far the results obtained can be generalised. Phenomena that were observed in a particular place at a particular time may not appear in other circumstances. In our approach we investigate large samples to make our results as convincing as possible. In addition to that we provide teachers with a tool they can use to find out whether our observations also appear in a particular learning group.

Method

Instruments

Multiple-choice items from examination boards in the UK and the US formed the basis for constructing the test items used in this study. The newly developed test items had the format of either multiple-choice or free response questions.

Two sets of questions were used. Question 1 is a representative example of a set of items in which students are asked to predict which of the given molecules could form hydrogen bonds. Question 2 represents a set of items in which students are required to predict the boiling points of the given substances relative to each other.

Question 1:

In which of the following compound(s) is hydrogen bonding likely to occur?

NH_3	CH_3F	CH_3OCH_3
(1)	(2)	(3)

[A] (1) only

[B] (2) only

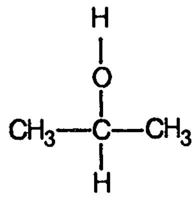
[C] (3) only

[D] (1) and (2) only

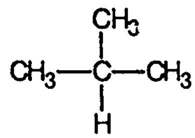
Question 2:

Which one of the following compounds has the highest boiling point?

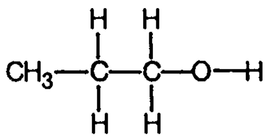
(1)



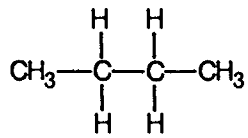
(2)



(3)



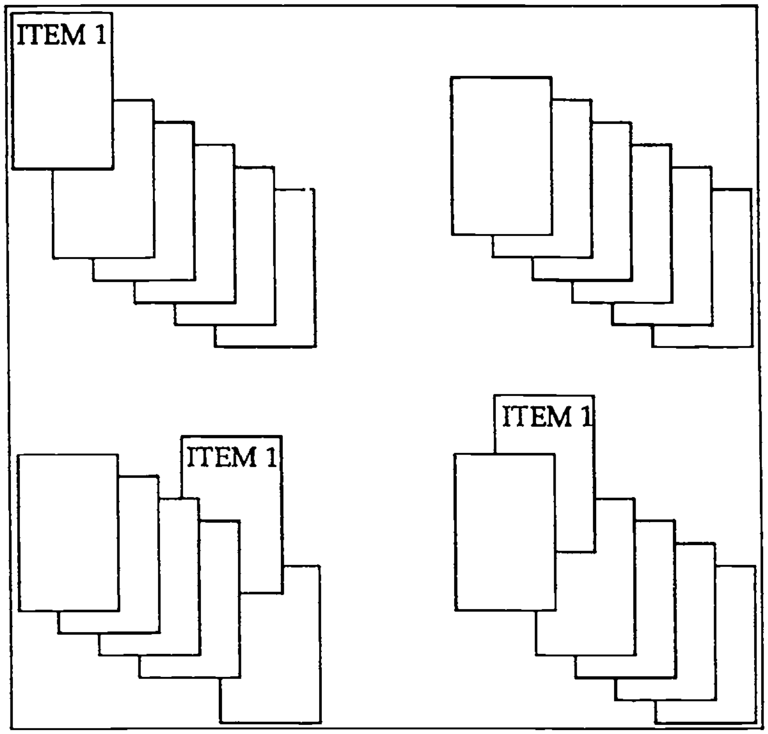
(4)



Design

The present investigation was part of a major project. Fourteen questions on boiling points and hydrogen-bonding as well as 106 items on other topics were administered. Each student received a package of six items to be answered in one school period. The test items were randomly assigned to the students and to the six positions in the test packages. Students did not receive more than one item on each topic (Fig. 1). The packages were assigned to 4,846 senior high school students. Each question was solved by approx. 200 students.

Figure 1: Random distribution of the test items to the packages and the position within the packages



Data collection and sample

The tests were completed in the school year 1994/5 by 4,846 German senior high school students. The curriculum for grades 12 and 13 is divided into elementary and advanced courses. The number of course hours per week is 2 to 3 for elementary and 5 to 6 for advanced courses.

Teachers volunteered for the investigation. Therefore, the test population is not a random sample with regard to statistical methods. For each option of the questions it was counted how many students had chosen this answer. Additionally, students' comments on the options were gathered.

Results and Discussion

Table 1 depicts the distribution of answers to Question 1.

Table 1: Distribution of grade 12 and 13 students' answers among the options for Question 1. Elementary courses (e), advanced courses (a)

Course	Options chosen, in %					Number of students
	A*	B	C	D	No answer	
e	27	4	34	22	13	112
a	20	7	31	29	13	82

The correct answer is A. Relatively few students arrived at this solution. At the same time, relatively few students did not answer at all. This could mean that students were quite confident they could resolve the question, but they seem to have been unaware of its degree of difficulty. Table 1 shows that there was a preference for distractors C and D.

Question 1 was also administered as free response item. In that version students preferred formulae 3, as well as a combination of 1 and 2 as incorrect answers. Hence, the distractors of the multiple-choice version seem to cover possible incorrect answers.

We were particularly interested in students' reasons for their answers. Three characteristics of molecules have to be considered for a full correct answer to Question 1. Hydrogen bonding is only possible if:

- the molecules of the compound contain a highly electronegative atom,
- hydrogen is directly attached to this electronegative atom so that the bond is polarized, and
- the electronegative atom has a free electron pair to which the hydrogen atom of an adjacent molecule can be attached

Comments of the students who chose the correct answer show that they recognized the necessity of a polar bond between hydrogen and the electronegative elements nitrogen, oxygen and fluorine. Here is a typical comment for the correct answer, A, of Question 1:

> H-bridges can form between highly electronegative substances like O, N, F if hydrogen is bonded to them. Due to of the strong electronegativity a dipole is created.

Apparently, the third criterion, namely the availability of a free electron pair is not explicitly mentioned. This criterion, however, is not absolutely necessary to pick the correct one of the three molecules.

The majority of students preferred distractor C. The tenor of their reasons was:

> Only CH_3OCH_3 can form hydrogen bonds because it is the only compound containing hydrogen and oxygen.

In Question 1 the formulae NH_3 / CH_3F / CH_3OCH_3 were given in the stem of the question. In a similar item HF / CH_3OCH_3 / $N(CH_3)_3$ were offered for students to choose from. In these items a lot of students preferred CH_3OCH_3. Perhaps this molecule reminded students of water molecules (see Figure 2) which are often used as an introductory example of hydrogen bonding in chemistry lessons. It could be detected in some comments that this was indeed the case. Apparently, students looked for a criterion that helped them decide whether or not a molecule can form hydrogen bonds. The fact that the compound contains oxygen seemed to be an obvious criterion, which led them to CH_3OCH_3. Thus, students only observed the first of the aforementioned three criteria for hydrogen bonding, limiting it to oxygen.

Figure 2: Similarity between water and dimethyl ether molecules

In some items of this set students arrived at the correct answer even though they applied this incorrect strategy. These were the items in which the three options were H_2O / CH_3F / $N(CH_3)_3$ and CH_3OH / HF / $N(CH_3)_3$. This clearly indicates that questions whose correct answer was a molecule containing oxygen had to be rewritten because an incorrect strategy must not lead to the correct answer.

It can be seen from Table 1 that quite a number of students chose distractor D of Question 1. The following comment is typical of students' reasons for D:

> Because fluorine and nitrogen are very electronegative and hydrogen can therefore build intermolecular forces with these two substances.

Here, the first of the three criteria mentioned above was mainly taken into account. In some instances the third criterion also came in. Apparently, it was students' strategy to look for an electronegative element. The electronegativity increases from nitrogen to oxygen to fluorine. However, students did not always recognize this order. In some items on hydrogen bonding they preferred the two most electronegative elements fluorine and oxygen. In Question 1 they also chose the compound containing nitrogen, but not the oxygen compound. If students consistently used the order of electronegativity to solve this question they could be expected to choose CH_3F and CH_3OCH_3 or all three compounds. However, this was not observed in the answers to the free-response version of Question 1.

The results for Question 2 indicate what strategies students used to predict the relative boiling points of simple organic compounds. Table 2 shows the distribution of answers:

Table 2: Distribution of grade 12 and 13 students' answers among the options for Question 2

Formula chosen, in %							Number of
1	2	3	4	1 & 3	other	No answer	students
5	11	30	20	9	9	16	246

The correct answer is 3. Relatively few students arrived at this answer. The number of students who did not answer was rather small, quite like in Question 1. This suggests that students were confident they could solve the question, but they may not have realized the degree of difficulty. Among the incorrect answers students preferred formula 4.

In order to solve Question 2 correctly students have to consider certain factors that influence the boiling points of organic compounds:

- All molecules given in Question 2 attract each other as a consequence of *van der Waals* forces. In addition to these forces the molecules of the alkanols can form hydrogen bonds.
- The magnitude of the *van der Waals* forces depends on the size of the molecules' surface. The surface increases with the molecular mass. If two molecules have the same molecular mass the size of the surface of straight molecules is larger than that of branched molecules.

Some of students' comments on the correct solution cover these factors quite well:

1 and 3 have the highest boiling points because of the effect of the hydrogen bonding force which is there because of the OH groups. 3 is highest because of the *van der Waals* force because the surface is larger as the molecule is shaped like a pipe.

Other comments on the correct answer do not clearly show that students really considered whether the molecule is branched or straight. They bring in a new argument, namely the chain length of the molecule. For example:

Compound 3 forms a polar OH group... which can "transform", together with other compounds of the same kind, into hydrogen bonds which have a high boiling point. Another reason is that long chained molecules have a higher boiling point than short chained ones.

Students may have learned something about the influence of the chain length in chemistry. A lot of textbooks contain charts or tables showing how the boiling points increase throughout homologous series. Consequently, Question 2 has to be altered so that the strategy of these students, which is an incorrect strategy, does not lead to the correct answer.

Students' comments on incorrect answer 4 also indicate that they considered the chain length. Their opinion apparently was that the length of the carbon chain determines the boiling point, as reflected in the following comment:

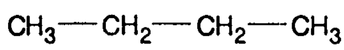
Butane - because the boiling point depends on the number of C atoms.

The idea that boiling involves cracking bonds within the molecule seems to be quite common among students. Unfortunately, this idea does not systematically lead to a particular incorrect answer.

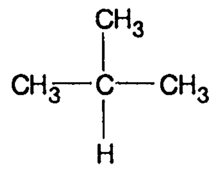
Question 2 was revised according to the results discussed above.

Question 3

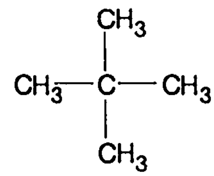
Which of the following compounds has (have) the **lowest** boiling point(s)?



(1)



(2)



(3)

[A] Compound (1)

[B] Compound (2)

[C] Compounds (1) and (2)

[D] Compounds (2) and (3)

A preliminary result shows that students preferred distractors A and D (Table 3).

Table 3: Distribution of grade 12 and 13 students' answers among the options for Question 3. Elementary courses (e), advanced courses (a)

Course	Options chosen, in %					Number of students
	A	B*	C	D	No answer	
e	40	18	10	20	12	82
a	33	30	8	23	6	66

Conclusions

Students are likely to have difficulties predicting whether a given molecule forms hydrogen bonds. They may not consider that not only oxygen, but also other electronegative atoms can be involved in a hydrogen bond. Also, they may not take into account that hydrogen has to be directly bonded to an electronegative atom to make hydrogen bonding possible. To put it more generally: they did not observe all criteria that are needed for a correct prediction.

Students also have difficulties predicting the relative boiling points of simple organic compounds. They incorrectly use the length of the carbon chain as a criterion for predicting the boiling point instead of differentiating between branched and straight molecules.

It became apparent that in some cases it was possible for students to arrive at the correct answer using an incorrect strategy. Consequently, these items need improvement.

Implications for Research and Teaching

This study shows that systematic development of test items is crucial to avoid that students using incorrect strategies arrive at the correct answer. Tests that do not meet this criterion could produce misleading results. The experience gained in this study should be used in future empirical research.

The multiple-choice items we developed can assist in the process of helping teachers use the findings of research in the classroom. The alternative of teachers interviewing their students is more time consuming and requires substantial training.

References

Gabel, d. L., Samuel, K. V., and Hunn, D. (1987). Understanding the particulate nature of matter. Journal of Chemical Education 64, 695 - 697.

Griffiths, A. K., and Preston, K. R. (1992). Grade-12 students' misconceptions relating to fundamental characteristics of atoms and molecules. Journal of Research in Science Teaching 29, 611 - 628.

Novick, S., and Nussbaum, J. (1978). Junior high school pupils' understanding of the particulate nature of matter: an interview study. Science Education 62, 273 - 281.

Osborne, R. J., and Crosgrove, M. M. (1983). Childrens' conceptions of the changes of state of water. Journal of Research in Science Teaching 20, 825 - 838.

Pereira, M., and Pestana, M. (1991). Pupils' representations of models of water. International Journal of Science Education 13, 313 - 319