Paper

Ideas Underpinning Success in an Introductory Course in Organic Chemistry

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Abstract

Students coming to university chemistry courses have often been taught a considerable amount of organic chemistry at school level and may bring to their university course important ideas. These ideas are discussed in the context of the Scottish Higher Grade Chemistry course. The extent to which these ideas have been understood was measured with 367 first year chemistry students before the students started their first organic chemistry course at university, using structural communication grid questions. Their understanding was related to their performance in the class examination at the end of the course. It was found that bond polarity was the area of greatest difficulty, with problems also arising from the student understandings of functionality and stereochemistry. What this study has shown is that certain ideas in school chemistry are well established, and others are not so well established, and that performance in a first level chemistry course in specific areas of organic chemistry reflects the grasp of the underlying ideas gained from school. This emphasises the importance of knowing what ideas pupils bring with them from school courses and how they came to gain these ideas. It also pinpoints some topics that may need to be developed further before introducing new organic chemistry ideas.

Introduction

Organic chemistry has gained importance in general education in secondary schools during the 20th century and this has had effects on higher education courses. Students at the University of Glasgow in their first year of study of chemistry take a course in organic chemistry covering the various functional groups and the general physical and chemical properties of organic compounds. The course is taught mechanistically, seeking to show the students why the various groups of organic compounds behave in the way observed. Reactivity and stereochemical aspects are introduced where appropriate. Students are encouraged to ask questions such as, “what class of organic compound is this?” “what kind of reaction can I expect it to undergo?” “are there any specific aspects to the reactivity of the compound that I need to bear in mind when deciding on the likely product(s) of the reaction?”

One of the major organisational principles of first year organic chemistry is functionality. In high school and university chemistry courses, textbooks usually present the chemistry by functional groups. Although students may memorise these groups, confusions often occur. It is not easy to see how functional groups can be *understood* although the properties of these groups can be presented in such a way that they make sense. Experience and practice is needed to enable the student to gain confidence with functionality. At school, structure is often presented before reactions are discussed, while, in a university course, the third ‘layer’ of mechanistic rationalisation is frequently added, along with a more sophisticated presentation of stereochemistry.

Inevitably, organic chemistry can be somewhat like a foreign language for first year students. Students must learn the vocabulary (names, functional groups) and the grammar (reactions, mechanisms) in order ultimately to develop a rudimentary style of composition (mechanistic explanations, evidence of structures). The mechanistic approach is an attempt to present a bewildering array of information in such a way that an underlying structure and rationalisation can be perceived and understood.

Historical Perspective

In the 1960s, there were many science curriculum projects at school level and, in Scotland, new chemistry syllabuses emerged in 1962 at school level. The Scottish Alternative Chemistry syllabus[1] was fully evaluated in the late 1960s[2]. A common feature of such syllabuses was to present an updated content in a logical order[3, 4, 5] and organic chemistry assumed a higher profile.

One of the major aims in all these curriculum and syllabus developments was to promote student *understanding* of the basic chemical concepts. Much is now known about difficulties in understanding concepts in science curricula and it has been argued[6] that a better approach might be to present the material in an order that takes into account the psychology of the learner rather than the internal logic of the subject which may only be apparent to relatively advanced learners.

Early studies on the Scottish syllabus showed that topics like esterification, hydrolysis, condensation, saponification, and carbonyl compounds posed problems[7] while a few years later, the problem of recognising functional groups was explored.[8] As a result of this early work, the presentation of organic chemistry at school level was modified in the Scottish system and this was reflected in the new textbooks.[9] At the same time, ideas were being developed to explain *why* the problems existed where they existed, in terms of the way the learner handles information.[10]

Underlying Ideas

This project seeks to focus on the learning of organic chemistry at first year university level. In looking at a first year university course, it is important to recognise that students come with experience gained at school (the Scottish Higher Grade). Some of this is information that they have remembered, but of greater significance is the grasp of the ideas that underpin organic chemistry, these ideas coming from their school experience.

At school level in Scotland, laboratory work and taught material are highly integrated. Nonetheless, it is still not always easy to link the molecular understanding to observations. This point was well made by Johnstone[11] when he pointed out that understanding chemistry involves working at three levels: the level of the macroscopic (phenomena which are open to the senses); the level of the sub-microscopic (the molecular level); and the level of the symbolic (the use of chemical and algebraic equations to represent or describe a phenomenon). The point that Johnstone was making is that it is difficult for the new learner to operate easily at all three levels simultaneously. However, in the learning of organic chemistry, it is customary to present the material at the start in symbolic form (symbols and equations) with reactions being interpreted at the molecular and electronic level by means of mechanistic representations.

Another weakness of the school presentation lies in the way organic chemistry is laid out. The entry point is through hydrocarbons, often related to the oil industry. This moves on into cracking and polymerisation. Quite inadvertently, the emphasis is placed on the carbon skeleton, with pupils having to remember the naming systems for hydrocarbon homologous groups along with basic ideas of isomerism. Later at school, and much more at university level, the emphasis moves to the idea of functionality in that reactivity is determined largely by functionality. In this, the carbon skeleton becomes much less important apart from, of course, its stereochemical features. Thus, pupils are taught initially to focus on the skeleton and then they have to switch to the functional groups. It is little wonder that, at times, organic chemistry becomes a strange world where the manipulation of the symbols C, H and O develops a confusing algebra all of its own.

Gagné[12] and Ausubel *et al.*[13] both agree that prior knowledge can influence learning, but there is a major difference in their ideas regarding the nature of the influence of prior knowledge. Gagné considered the optimum order to be teaching sub concepts on the way to developing higher concepts, leading to a hierarchy of learning. On the other hand, Ausubel considered that learning is an active process in which students construct their own meaning from new information. In other words, a concept has to be reconstructed when it passes from the teacher to the student and meaningful learning is an active process of transferring new knowledge into the existing knowledge in the individual's cognitive structure. Ausubel stated that: "If I had to reduce all of educational psychology to just one principle, I would say this: The most important single factor influencing is what the learner already knows. Ascertain this and teach him accordingly."[13]

Ausubel's emphasis was on meaningful learning. According to Ausubel *et al.*[13] and Novak,[14] learning will be 'rote' if the material to be learned lacks logical meaning or the learner lacks the relevant ideas in his/her own cognitive structure. This study seeks to offer some insights into the underlying ideas held by students in an attempt to pinpoint those areas where the problems are greatest.

This Study

The aim of this study is to focus specifically on some of the underlying ideas that students bring with them from school chemistry and to see the extent to which basic organic chemistry concepts are held in the long-term memory of first year students *before* they start their university organic chemistry course. The results will then be related to student success in the university course. Four underlying concepts were identified arising from the Higher Grade syllabus: the nature of the covalent bond; bond polarity; stereochemistry and the importance of molecular shape; and functionality.

Structure is absolutely critical when learning organic chemistry. It forms the basis for predicting and rationalising reactivity on the molecular scale and physical properties at the macroscopic level. The central theme of the teacher's approach at university level is to emphasise the relationship between structure and reactivity. To accomplish this it is necessary to choose a teaching strategy that combines the most useful features of the traditional functional group approach with one based on reaction mechanisms.

Such an approach aims to emphasise mechanisms and their common aspects as often as possible, along with the functional groups and the structural aspects, to offer to the students a meaningful insight into organic chemistry.

For this approach to work, it is important that students have a clear grasp of the underlying ideas: structure and stereochemistry, the ideas of bond and molecular polarity, and the nature of the chemical bond and formal charge. In this way, the student can make intuitive sense of mechanisms. Of course, students need to know, and recognise with confidence the important functional groups.

Chemists have devised various types of two-dimensional diagrams to represent three-dimensional structures. All these seek to present on paper what is a three-dimensional structure. Not all are equally effective in terms of the informational value they possess.[15] In work done many years before, Johnstone *et al.*[16] demonstrated that students needed to move backwards and forwards between two dimensional and three dimensional representations using physical models, illustrations and paper representations. Looking at molecular models is not enough; they have to be handled, rotated, and manipulated.

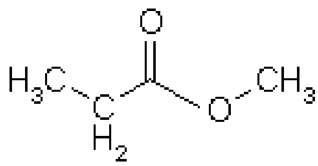
The stereochemistry of organic molecules is generally controlled by the 'rules' of geometry, coupled to the laws of electrostatic repulsion. This approach is well developed in one textbook for school use[9] but most texts do not develop these ideas at school level, and school leavers may not be able to relate the physical reality of the three dimensional structure to the two dimensional representations, some of which bear little relation to the actual molecular shapes.

There are many studies which look at issues relating to the three dimensional problem. Some have addressed the issue whether molecular models really contribute to the better understanding of the concepts of the atom and the molecule [17, 18, 19, 20] while others have used computer simulation.[21]

Baker and Talley[22] stated that: "An examination of the type of thinking that is required for mastery of chemistry indicates that visualisation of chemical reaction by the use of physical models is an important vehicle for the communication and analysis of chemistry concepts". In another report, Baker[22] noted that students find stereochemistry very difficult to grasp. He explained that this arises largely owing to the restrictions inherent in a lecture-theatre environment, where molecular shapes are necessarily drawn using the blackboard or paper. While large ball-and-stick molecules can be used to illustrate the idea of shape, mirror image and enantiomers, he concluded that the best teaching exercise for the students is for them to manipulate the models themselves, confirming Johnstone's findings.[23] Many[21, 24, 25, 26] have used molecular modelling in an undergraduate chemistry curriculum and have argued that they offered real benefits to students in understanding concepts.

However, in many models of learning, a *mechanism* for learning is missing.[27] Such a mechanism of learning can show us what the reasons are for the difficulties in understanding certain concepts in organic chemistry or in science generally and can help students' teachers/lecturers to avoid problems. Such a mechanism can be found in an information processing model.[28] This draws on other models of learning but offers interpretation in terms of information flow and processing.

Johnstone[29] and Johnstone and El-Banna[30] confirmed that working memory space has a very limited capacity and, when exceeded, this can make learning almost impossible. When this is applied to the learning of organic chemistry, the problems are readily apparent. Take a 'simple' molecule such as $CH_3CH_2COOCH_3$ (methyl propanoate), which can be represented as



If a person who knows no organic chemistry was presented with this structure for ten seconds and then was asked to reproduce what he saw, the task would probably be well beyond his capabilities. This is simply because the amount of information in the structure is well beyond the working memory space capacity of the learner.

However, another person with some knowledge of organic chemistry might be able to group the (CH_3CH_2) group as a 'chunk' (with or without the name 'ethyl') and recognise the ester functional group (COO) as a' chunk' and the final methyl group as a third 'chunk'. This has the potential to reduce the load to three pieces only. Provided that the linkages can be appreciated, this gives the person a chance of holding the formula within the capacity of the working memory. An experienced chemist would see the structure as one unit or 'chunk' (methyl propanoate) and would be able to store, reproduce or manipulate such structures easily within the working memory. The novice learner has no such ability.

However, while working memory is important, what is already held in long term memory is also important for new learning. What is already known provides a filter to select and interpret new information. In addition, new information, if it is to be understood meaningfully, has to be linked on to information and concepts already held in long-term memory.

Generally speaking, learning involves the linking and interpreting of incoming information with what is already known by an individual.[13] As each person has different stores of knowledge in long-term memory, each may interpret incoming information differently. If the new information cannot be linked on to previously held ideas in a meaningful way, then the student may resort to rote memorisation. None of these, of course, represents acceptable learning outcomes from the perspective of the teacher.[31, 32]

Scottish School Chemistry

Students are taught organic chemistry from S3 (age around 14) in Scottish secondary schools. At the start, the work is centred on hydrocarbons, the oil industry and related materials such as plastics. Later, they start a brief look at food chemistry, with some reference to ethanol and ethanoic acid. While ideas like isomerism are considered, there is a very limited development of ideas of functionality and organic reactivity.

In the Higher Grade course (age around 16-17), organic chemistry is treated more systematically. The reactions of various functional groups are discussed, especially those of alcohols, acids, aldehydes and ketones. Often there are attempts to emphasise patterns in properties and reactions. Nonetheless, pupils can resort to memorisation in an effort to achieve examination success.

Examination performance at school level suggests that students cope fairly well with carbon chains, simple naming and isomerism. However, the move towards organic reactivity and the focus on functionality has less to do with the initial emphasis on carbon skeletons. Another problem may arise because organic reactions seem different from other reactions in that, in many reactions studied, things seem to proceed slowly (compared to many ionic solution reactions already met). While the nature of covalent bonds and bond polarity have been developed, the significance of these ideas in the context of organic reactivity may not always be apparent to students meeting organic reactions for the first time.

The covalent bond and the ionic bond are introduced early in the syllabus at school. Bond polarity and the polar covalent bond are often taught later, perhaps implying that the polar bond is less common. The idea that bonds can be made to be polarised by external electrophilic or nucleophilic reagents is not really developed much at the school level. At this stage, there is little concept of organic reaction mechanisms in general, including the stereochemical aspects of reaction mechanisms.

While there is no specific emphasis on reaction mechanism at school courses, students should have some understanding of the following key basic concepts related to organic chemistry:

(i) The nature of the covalent bond
(ii) Bond polarity
(iii) Stereochemistry and the importance of molecular shape
(iv) Functionality

To explore what the students bring with them on these four concepts as they face their first university organic chemistry course, a test was devised, mainly in a structural communication grid format.[32] Their performance in this was related to the students' performance in their class examination.

Structural Communication Grids

Structural communication grids have been developed and used by several researchers.[33] In a recent study,[34] the strengths and weaknesses of structural communication grids as assessment tools for school pupils have been studied. Structural communication grids involve data being presented in the form of a numbered grid and students being asked to select appropriate boxes in response to set questions. Use of these grids gives an insight into sub-concepts and linkages between ideas held by students, so that understanding can be assessed.

One of the advantages of this technique is that the contents of the boxes can be words, phrases, pictures, equations, definitions, numbers, formulae and so on. The content of the boxes can be varied, so that they can be made suitable for visual as well as verbal thinkers. Numerous questions can be asked and the format almost completely eliminates the problems of guessing, because the student does not know in advance how many boxes are needed for an answer. Credit is also given for partial or incomplete knowledge. Grid questions can be designed to assess a student's degree of understanding of the topic and can be offered as a self-assessment technique that could help pupils identify their weaknesses and strengths. Selected wrong answers can point to particular misunderstandings and the flexibility of the structural communication grids as an assessment and diagnostic tool is enormous. The use of structural communication grids in a research context has been discussed by Reid.[35]

The Experimental Study

This study had the following two aims:

1. In the light of the organic chemistry taught at school and the way it is presented, the aim is to explore the level of understanding of four underlying concepts just before first year students start their first organic course at

university. Of course, it is recognised that there is a time gap between the school study and the time of the measurement of these conceptual understandings.

2. Following this, the second aim is to relate this understanding of underlying concepts to performance in the chemistry examinations used in the first year course at Glasgow.

The study was conducted in two stages:

The first stage of the experimental works consisted of the structural communication grid test. The test involved four main questions, three of a grid nature. The test, therefore, covered only *some* aspects of the four underlying concepts. Care was taken to select the questions so that they related to school syllabus coverage and that language and representations used were appropriate. The test was discussed with experienced secondary teachers and this was followed by consultation with the lecturer in organic chemistry responsible for the students concerned.

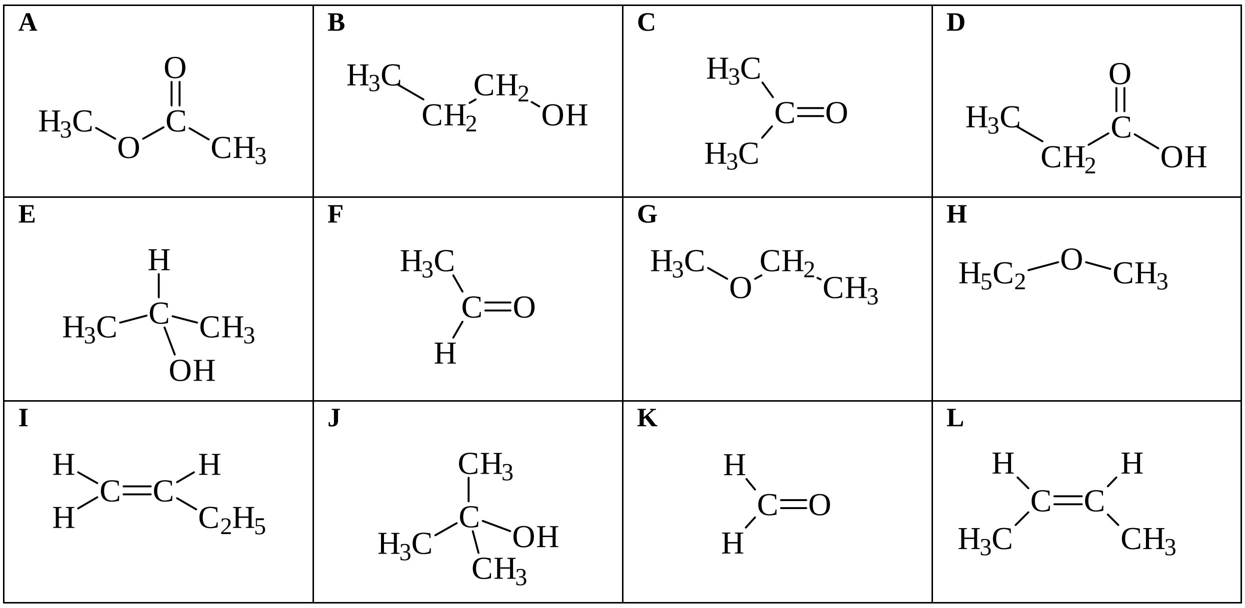
Question 1 mainly explored functional group recognition, question 2 explored stereochemical features, question 3 explored the concept of polarity, while question 4 (which was open-ended) looked at the nature of the chemical bond. The test is shown in full when the results are discussed later.

In all, 367 students completed the structural communication test, representing 82% of this particular first year chemistry class. The test was not timed. The students were mostly from Scottish comprehensive schools, coming to university with a Higher Grade pass in Chemistry at 'A' or 'B'. The test was marked in two ways. Firstly, responses to each item were coded and the data stored in a spreadsheet. The aim was to gain maximum insight into the strengths and weaknesses of the students understanding of the underlying concepts. Using the spreadsheet, the test was re-marked to give a total mark for each underlying concept. These were then related in turn to the examination performance by each student, using an examination given by the department at the end of the semester. These results are discussed below in detail. It is important to note that the purpose of the examination used by the department was not the same as that of the structural communication grid test. The former sought to test overall performance in the organic course while the latter looked at underlying ideas brought from school.

Discussion of Results

The patterns of results from the sample for each part of each question are now discussed.

(1) Look at the boxes below and answer the questions that follow.
(Boxes may be used as many times as you wish)



Select the box(es) which show the structure of:

		Correct responses
(a)	An isomer of the compound shown in box G	B, E
(b)	A secondary alcohol	E
(c)	An aldehyde (alkanal)	F, K
(d)	A compound which reacts with bromine to form 1,2-dibromobutane	I
(e)	An ester	A

In question 1(a), the students had two isomers to identify and 33% were successful, with a further 14% finding one of the two. Another 30% identified both but added a third option, many selecting an identical molecule that was shown in a different way.

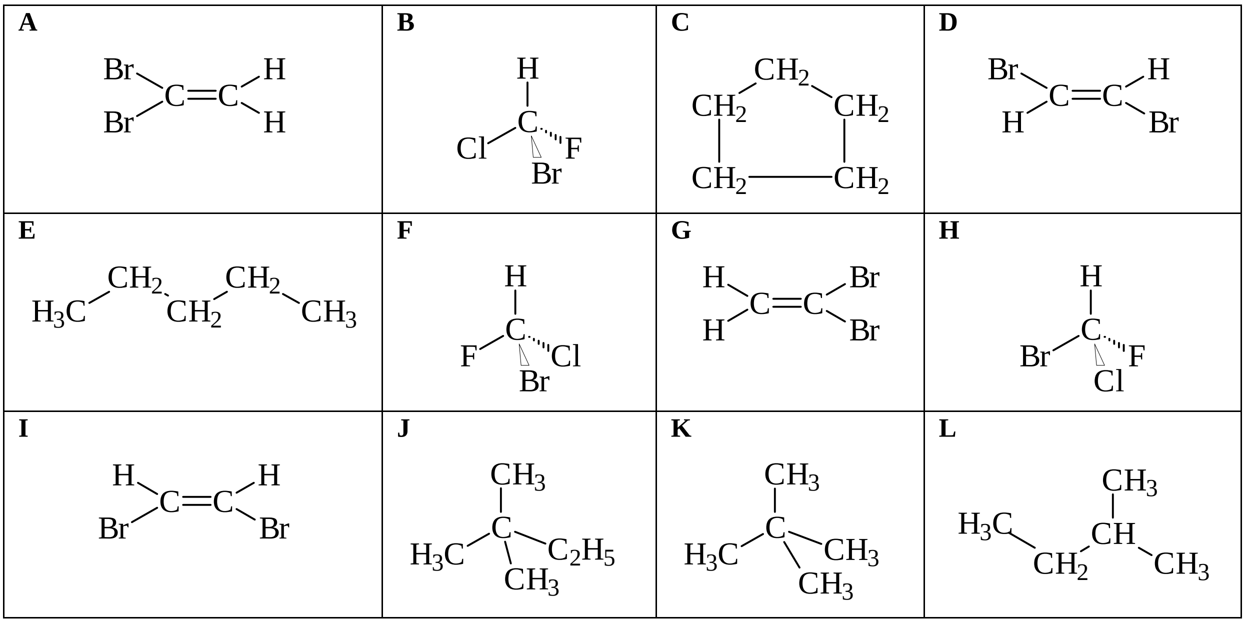
In question Q1(b), students were asked to select the box(es) which contain the structure of a secondary alcohol. 61% could identify it correctly but a further 11% identified a tertiary alcohol in addition. Alcohols are emphasised in the school syllabus and, happily, two thirds were giving the right answers.

In reply to Q1(c), only 29% could identify the aldehydes (alkanals) correctly. A further 14% did not see formaldehyde (methanal) as an aldehyde (alkanal) while other functional groups were confused with aldehyde (alkanal): ketone 15%; acid 13%; ester 9%; propanol 3%. Over 17% offered no answer at all. Overall, the majority was showing confusion over aldehydes (alkanals).

In Q1(d), only 46% could identify the compound (a 1-alkene). Nearly 23% wrongly identified the alkene that would give a 2,3-dibromo compound, while another 14% identified this alkene compound *and* the right answer. One way of interpreting the pattern of results is to suggest that the students, when school pupils, did not really understand what was happening during such an addition reaction. They would be aware that the bromine solution was decolourised and would have been told that a dibromo compound was formed. The specific features of the addition were, however, not so clearly grasped. Again, this may have significance when further addition reactions are met, and elimination reactions are introduced.

In Q1(e), only 54% identified the ester correctly, 18% incorrectly choosing an acid and 12% incorrectly choosing an ether, with 11% not offering any answer. It is perhaps easy to see the confusion between an acid and an ester in that both contain the -COO- linkage. However, the ether does not contain this linkage but the -C-O-C- linkage. Is this a visual confusion, or is it that the presence of oxygen *in a linkage* which causes the difficulty, or both? It is even possible that the similarity of names (ester and ether) is a source of confusion.

(2) Look at the boxes below and answer the questions that follow.
(Boxes may be used as many times as you wish)



Select the box(es) which contain:

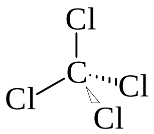
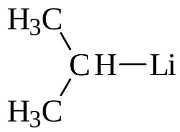
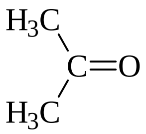
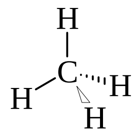
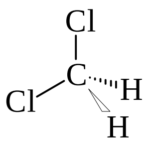
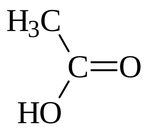
		Correct responses
(a)	An isomer of the molecule shown in box A	D, I
(b)	An isomer of the molecule shown in box D	A, G, I
(c)	An isomer of the molecule L	E, K
(d)	A molecule which is identical to the molecule shown in box F	H

In question Q2(a), 56% were confident about isomerism here with a further 33% with a partial understanding. When the various isomers of the dibromoethene were considered taking account the possibility of cis-trans isomerism (question 2(b)), the number who grasped this fully dropped to 38%. A further 20% demonstrated that they did not see the lack of rotation around a double bond.

In Question 2(c), surprisingly, 44% had difficulty with alkane isomerism. There was confusion, with K often omitted and, sometimes, J added and with straight chain compounds when compared to a branched compound. This may reflect the way the molecules were presented in that the representation at school level used a different system from that encountered in the test. The system used in the test was chosen to follow the system that students would meet in their organic chemistry lecture course. Informal evidence from school teachers that pupils seem to be able to manage alkane isomerism with few problems would support the argument that the different method of representation might have been a factor causing confusion. This points to a serious problem inherent in all forms of representation; at school level, the molecules are drawn ‘flat’, with all the bond angles at right angles, while the system used here made some attempt in representing the correct geometrical shape.

Q2(d) moved on to optical isomerism, a topic not specifically covered at school at Higher Grade, the level used as the basis for entry. However, some would have studied at Advanced Higher Grade where this topic is covered.. The aim here was to explore whether the students could ‘see’ this three-dimensional aspect of stereochemistry. As expected, optical isomerism posed problems, with only 30% being successful. The main error for those who responded was confusion between optical isomers and molecules, which were identical but were presented from a different angle, 41% making this selection, with a further 27% including both right and wrong answers. The perception of three dimensions is known to cause problems.[23, 24, 26] This item confirms the need for great care in presenting reactions where such stereochemical features are important. However, if many of the students had not met the idea, it would difficult for them to look for such a stereochemical feature.

(3) Look at the boxes below and answer the questions that follow.
(Boxes may be used as many times as you wish)

A 	**B** C_2H_5OH	**C** 
D 	**E** H_2O	**F** 
G 	**H** NH_3	**I** 

Select all the boxes:

		Correct responses
(a)	Where the molecules can form hydrogen bonds	B, E, H, I
(b)	Which contain molecules with a carbon atom which is at the *positive* end of a polar bond	A, B, D, G, I
(c)	Which contain *molecules* which are polar	B, C, D, E, G, H, I

In Q3(a) the students were asked to identify molecules which can form hydrogen bonds. Only 21% noted all four, but a further 30% managed three of the four, the missing one usually being ammonia. This was a surprising omission in that the school course did deal with ammonia. Hydrogen bonding is taught at school with fairly specific molecules used as illustrations. The concept has clearly not been grasped in an overall sense.

In Q3(b), in seeking to identify molecules with the carbon at the positive end of a polar bond, considerable confusion was observed. Only 7% identified all the molecules, with a further 15% missing one of them. Many more managed three of the five answers (10%) while large numbers identified one (16%) or two (23%) correct answers. However, 22% offered no answer at all. Clearly, this is an area of very large confusion. One of the problems may lie in the way bonding ideas are developing at school level, with ionic and covalent being taught as a kind of 'norm' and polar covalency then being added later (leaving, perhaps, a suggestion that this is not so normal?).

A similar level of confusion emerged when students were asked in Q3(c) to select and identify all the boxes that contain molecules that are polar, with only 7% being totally successful. 11% wrongly identified tetrachloromethane as a polar molecule and 8% identified methane as a polar molecule. Large numbers offered a limited range of correct answers. 13% offered no answer.

This is an area of major difficulty. Part of it arises because hydrogen bonding is related specifically to water and alcohols – the concept is not presented in a broad sense at school level. There is little emphasis at school (up to Higher grade) on bond polarity in carbon compounds (although the polar bond in general is covered) and this shows clearly in the results. This poses fundamental problems when students are faced with their first university organic course when they will meet mechanisms of reactions in some detail. The failure to grasp the fundamental notion of bond polarity may pose problems to some students in making sense of mechanistic interpretations.

The fourth question was not in grid format. It asked the students to explain what the line between two carbons represented and what the double line between two carbons represented. 57% correctly indicated two and four electrons respectively, with a further 13% specifically referring to electrons without a clear reference to the numbers involved. This underlying idea seems reasonably well established although it has to be noted that 30% did not show any grasp of what a bond line meant.

Overall Patterns

Four underlying ideas have been explored by means of the structured communication grid test. Specific areas of weakness have been identified, with bond polarity being particularly problematic. Inevitably, as molecular complexity increases, so difficulties increase. Such difficulties may be reduced when students 'see' molecules in a more holistic way, recognising functional groups and structural features with confidence. It is clear that this was not always happening.

It is important to gain a view of organic chemistry through the eyes of incoming students. Some of the inadequate grasp of key ideas (e.g. bond polarity) is likely to make further learning more difficult. It was also likely that the different ways schools and universities represent structures could be causing problems. It could be easy to suggest that the school presentation should change to be more like that used later. This might be a more ideal situation but it has to be recognised that it would be difficult to achieve.

Correlation with Class Examination Performance

This comparison involved 295 students, 66% of those enrolled in the class. The 295 were those who completed the structural communication grid test and who had completed *both* [organic] questions in the class examination at the end of the semester, with a choice of questions being offered. Of course, it is recognised that this may have selected those students who were more comfortable with organic chemistry.

The examination was scored by the department lecturers in the normal fashion, following a marking scheme. These marks were compared to the scores obtained from the structured communication grid. Pearson correlation was used to establish the relationship between the scores obtained in the structural communication grid test and the examination used by the department. This examination contained one section on organic chemistry and there were two questions (questions 5 and 6 of the whole examination). Each part of questions 5 and 6 is now outlined very briefly. For the purposes of this study, all the student scripts were examined and their scores for each part of each organic question were recorded on a spreadsheet. It is worth remembering that the student group was an able group, and almost everyone had obtained an 'A' or 'B' pass in Higher Grade Chemistry from school as well as good grades in other subjects.

In Q5(a), students were asked about the systematic name of an alkene (2-methylbut-2-ene); 95% gained full marks.

In Q5(b), students were asked about cis/trans isomerism in an isomer of 2-methylbut-2-ene. The responses here were weaker, only 51% giving the correct answer and drawing the isomeric structures correctly.

In Q5(c), students were asked about the reactions of the 2-methylbut-2-ene with bromine, hydrogen bromide, and potassium permanganate. Only 57% offered correct answers.

In Q5(d), students were asked to draw the mechanism of addition of HBr to the 2-methylbut-2-ene, using curly arrows. 63% gave an acceptable answer

In In Q6(a), students were asked to draw in all the lone pairs of electrons missing from six given molecules or ions; 69% gave correct answers.

In Q6(b), students were asked about the treatment of a bromoalkane with hydroxide and they were told that a mixture of two products is formed. Many organic concepts were being tested in this question and the students response here was also relatively weak (57%). This is really the area of major difficulty in organic chemistry and new students always find difficulty with reactions and mechanisms of organic chemistry. The astonishing fact observed here is that some students could not identify which of two atoms in a polar covalent bond was the more electronegative! This confirms the poor grasp of bond polarity from school observed in the structural communication test.

A comparison was made between the student's performance in the questions from the structured communication grid, used *before* the students started their first organic course (questions 1-4) and the examination *after* the student had finished their first year organic chemistry course (questions 5-6).[1]

The hypothesis is that the grasp of key underlying concepts from school would predict future success in the mechanistically presented organic chemistry course at university. However, it is possible that any positive correlations can be explained simply by the ability of the students in chemistry or, indeed, their commitment to chemistry.

Correlation coefficient values were obtained for each part of each of questions 1 to 4 compared to each part of each of questions 5 and 6. They were also obtained for the questions overall and the discussion starts by looking at these overall correlations before exploring some of the more interesting details with separate parts of questions.

With a sample approaching 300, even quite low correlation values may be highly significant. Nonetheless, nonsignificant values were also obtained. This suggests that the correlations were *not* simply reflecting some kind of overall ability in chemistry. Indeed, many of the variations in correlations values obtained can be related to what was being asked and the underlying ideas specifically developed at school level.

When looking at the performance in questions 1 to 4 correlated with the performance in questions 5 and 6, positive highly significant correlations were obtained in each case. These are summarised in Table 1

Table 1 Correlation: Structural Communication Grid Questions and Examination Questions

N = 295	Question 1	Question 2	Question 3	Question 4
Question 5	0.26	0.22	0.34	0.19
	p < 0 001	p < 0 001	p < 0 001	p < 0 001
Question 6	0.21	0.22	0.30	0.20
	p < 0 001	p < 0 001	p < 0 001	p < 0 001

These correlation values are what might be expected. Of greatest interest is the observation that the *highest* correlations occur with Question 3, where it has already been shown that student confusions are greatest. It could be argued that these statistically significant correlations merely reflect general knowledge of chemistry or even general ability. However, when the correlations involving parts of questions are considered, correlation values approach zero are obtained in quite a number of cases. This suggests that the observed statistically significant correlation values *do reflect something more than knowledge of chemistry or general ability*. For example, Table 2 illustrates some places where low correlations were obtained.

Table 2 Some Non-Significant Correlations

N = 295	Question 1(a)	Question 2(b)
Question 5	0.08	0.09
	Not sig.	Not sig.
	Question 1(b)	Question 1(d)
Question 6	0.09	0.08
	Not sig.	Not sig.
	Question 5(b)	Question 5(d)
Question 1(d)	0.04	0.07
	Not sig.	Not sig.

In looking at the pairs of questions involved in each correlation, it is clear that the questions are testing

1 It is chance that question numbering worked out this way but, for simplicity, the numbers are used in the discussion: questions 1-4 coming from the structural communication grid and questions 5 and 6 from the departmental chemistry examination.

completely different skills although all are, of course, testing organic chemistry. The nonsignificant correlations show that the different skills are, indeed, *different* and not just reflections of some kind of overall ability. For example, question 1(a) deals with isomers of alcohols and ethers and this is completely unrelated to any parts of question 5.

Table 3 Question 1(d) and parts of question 5

N=294	Pearson r	Significance
Q5(a)	0.12	<5%
Q5(b)	0.04	ns
Q5(c)	0.16	<1%
Q5(d)	0.07	ns
Q5(e)	0.13	<5%
Q5(Total)	0.17	<1%

There are also some correlation values, which vary when separate parts of the questions are considered.

In Table 3, performance in question 1(d) in the structured communication grid is related to the five parts of question 5 of the chemistry test. 1(d) specifically relates to bromination across a double bond. Q5(a) and (b) test the name and structural isomerism of an organic molecule and, as expected, correlation values are not high. Q5(c) is testing the mechanistic understanding of bromination and hydrobromination across a double bond and, as might expected, highly significant correlation is found. Q5(d) is about the concept of drawing the mechanism of the addition of HBr to the double bond of an alkene as a Markovnikov addition using curly arrows. Here, the overall process is different. In fact, in Q5(d) many organic concepts are being tested but these were new to the students, not having been studied at school. It appears that success in the question about hydrobromination is not dependent on a grasp of the bromination process. Q5(e) was about ozonolysis of the double bond and, while not covered in school chemistry, the reaction is somewhat similar to bromination.

The performances in each part of question 2 of the structured communication grid were correlated with question 6 of the departmental test and the results are shown in Table 4.

Table 4 Question 2 and Question 6

N = 281	Pearson r	Significance
Q2(a)	0.18	<1%
Q2(b)	0.07	ns
Q2(c)	0.23	<0.1%
Q2(d)	0.14	<5%
Q2(Total Score)	0.22	<0.1%

Q2 in the structural communication grid test deals with stereochemistry. Q2(a) and Q2(b) both deal with isomerism in alkene molecules. Q2(a) involves simple molecular isomerism (1,1 and 1,2 substitutions) while Q2(b) also involves geometric isomerism. Q2(c) deals with alkane isomerism and Q2(d) tests to see if students could 'see' the idea of mirror images.

Q2(b) is dealing with geometrical isomerism which is not covered at all in Q6 - hence the absence of significant correlation. Q2(a) and (c) both deal with structural isomerism and Q6(b) depends on this and the high correlation might be for this reason. This is confirmed when the correlations of 2(d) with Q6(b) is calculated and found to be 0.22 (sig at <0.1%). Q2(d) deals with chirality and the idea of mirror images. There are no chirality ideas involved in Q6 at all and the observed lower correlation is as expected.

Sometimes, correlation values were higher. For example, the performances in each part of question 3 of the structured communication grid were correlated with question 5 of the departmental test. The results are shown in Table 5.

Table 5 Question 3 and Question 5

N=295	Pearson r	Significance
Q3(a)	0.15	<1%
Q3(b)	0.29	<0.1%
Q3(c)	0.23	<0.1%
Q3(total)	0.34	<0.1%

Q3(a) deals with hydrogen bonding which is not tested explicitly in any way in Q5 of the chemistry test. It is at first sight surprising that there is any significant correlation at all. However, the ideas behind hydrogen bonding involve an appreciation of bond polarity and this is important in answering a mechanistic question like question 5. The very high significance of the correlation values for Q3(b) and Q3(c) are to be expected since most of question 5 depends heavily on an understanding of bond polarity which was tested in these questions. It would appear that understanding bond polarity is a very critical skill and it is very obviously required in many parts of question 5.

Summary

Significant correlations must be interpreted with caution, but the absence of significant correlations is interesting and, indeed, most of the variations in correlations values obtained can be related to what was being asked and the underlying ideas specifically developed at school level. Of course, the results could be interpreted by suggesting that those who had understood the underlying ideas at school level were also capable of higher levels of performance in a university course. However, again, the absence of significance in some cases tends to undermine any argument based on some kind of overall ability at chemistry.

The highest levels of significance were observed in the areas related to bond polarity. The problems relating to the way this is presented in the school syllabus order have been discussed and it is very clear that a mature understanding of the nature of polarity and of induced polarity are important in making sense of a mechanistic presentation of organic chemistry.

Functionality is very important in understanding organic reactivity. The school syllabus approach, with its emphasis on the carbon skeleton at early stages, poses some problems in developing confidence in functionality. It may well be that such experience in handling functionality can act as a 'chunking' device, reducing potential overload on the working memory when studying organic reactions and mechanisms.

Structural ideas are also important. There is a problem with the school syllabus expecting molecules to be drawn flat on paper, with bond angles apparently at 90˚. The university course represents molecules on paper in such a way that the real stereochemistry is more apparent. In addition, the school syllabus insists that all hydrogens are shown while practising organic chemists rarely show the hydrogen atoms. Three-dimensional visualization is not easy and the use of a working area where students can carry out tasks using models along with paper representations and other visual representations has been shown to help.[16]

Of course, school chemistry courses are not designed simply to prepare pupils to study chemistry at university or they ought not to be. Perhaps only about one fifth of those gaining a Higher Grade in Chemistry in Scotland will actually take any course in Higher Education that contains recognisable chemistry. What this study has shown is that certain ideas in school chemistry are well established and others are not so well established and that performance in a first level chemistry course in specific areas of organic chemistry reflects the grasp of specific underlying ideas gained from school. This emphasises the importance of knowing what ideas pupils bring with them from school courses[36] and how they came to gain these ideas. It also pinpoints some topics that may need to be developed further before introducing new organic chemistry ideas.

References

1. Chemistry at Ordinary and Higher Grades, Circular 512, Scottish Examination Board, Dalkeith, 1962.
2. A.H. Johnstone, *Studies in Science Education*, 1974, **1**, 21.
3. S.J. Hawkes, *J. Chem. Ed.*, 1992, **69**, 178.
4. N. Reid, *Staff and Educational Development Internationa*l, 1999, **3**(1), 71.
5. N. Reid, *Chemistry Education: Research and Practice in Europe*, 2000, **1**(3), 382. URL: http://www.uoi.gr/cerp/
6. A.H. Johnstone, *Chemistry Education: Research and Practice in Europe*, 2000, **1**(1), 9.
7. A.H. Johnstone and N.C. Kellet, *Educ. Chem*., 1974, **11**(4), 111.
8. A.H. Johnstone, and K.M. Letton, *Educ. Chem.*, 1982, **19**(1), 16.
9. A.H. Johnstone, T.I. Morrison, and N. Reid, *Chemistry About Us,* London; Heinemann Educational Books, London, 1981.
10. A.H. Johnstone and N.C. Kellett, N.C., *European J. Sci. Ed*, 1980, **2**(2), 175.
11. A.H. Johnstone, *School Science Review*, 1982, **64**(277), 337.
12. Gagné, R.M., *The Conditions of Learning*, 4th Edition, Holt, Rinehart and Winston, New York, 1985.
13. D.P. Ausubel, J.D. Novak and H. Anesian, *Educational Psychology: A Cognitive View*, 2nd edition, Holt, Rinehart and Winston, London,1978.
14. J.D. Novak, *Studies in Science Education*, 1978, **5**, 1.
15. V. Ferk,, Vrtacnik, M., Blejec, A. and Gril, A., 2002, *Intern. J. Sci Ed.*, **25**(10), 1227.
16. A.H. Johnstone, K.M. Letton and F. Percival, F., *Chem. Brit.*, 1977, **13**(11), 423.
17. A.G. Harrison and D.F. Treagust, *Science Education* 1996, **80**(5), 509.
18. A.G. Harrison and D.F. Treagust, *Science Education*, 2000, **84**(3) 352.
19. L. Grosslight, C. Unger, E. Jay and C. Smith, *J. Res. Sci. Teaching*, 1991, **28**(9), 799.
20. C.F. Copolo and P.B. Hounshell., *Journal of Science Education and Technology*, 1995, **4**(4), 295.
21. M.J. Sanger R.J. Phelps and J. Fienhold, *J. Chem. Ed.*, 2000, **77**(11), 1517.
22. S.R. Baker, and L Talley, *J. Chem. Ed.*, 1972, **49**(11), 775.
23. R.W. Baker, A.V. George, M.M. Harding, *Chem. Ed.*, 1998, **75**, 853.
24. M.B. Jones, B. Martin, *J. Chem. Ed.*, 2001, **78**, 867.
25. P.J. Smith, *J. Chem. Ed.,* 1978, **55**(1), 115.
26. J.B. Klassen, K.J. Graham and W.P. Muldoon, *J. Chem. Ed.*, 1999, **76**, 985.
27. A.H. Johnstone, *J. Chem. Ed.*, 1993, **70**(9), 701.

28. A.H. Johnstone, R.J. Sleet, and J.F. Vianna, J. F., *Studies in Higher Education*, 1994, **19**(1), 77.
29. A.H. Johnstone, *J. Chem. Ed.*, 1984, **61**(10), 847.
30. A.H. Johnstone, H. El-Banna, H., *Educ. Chem.*, 1986, **23**(3), 80.
31. W. Byers, *U. Chem. Ed.*, 2001, **5**, 1.
32. K.S. Taber, *Educ. Chem*., 1999, **36**, 136.
33. M. Bahar M., M.H. Hansell and A.H. Johnstone, *J. Biol. Ed.*, 2000, **34**(2), 87
34. A. Ambusaidi and A.H. Johnstone, *Chemistry Education: Research and Practice in Europe*, 2000, **1**(3), 323.
35. N. Reid, N., *Getting Started in Pedagogical Research*, Learning and Teaching Support Network, Liverpool, 2003.
36. G. Sirhan, and N. Reid, *U. Chem. Ed.*, 2001, **5**, 52