Crossword Puzzles as an Aid to Learning and Teaching Higher Chemistry

Dr Anthony Luke

Abstract

Crossword puzzles are being used in a range of disciplines as an aid to learning subject-specific vocabulary. Literature showing the use of crossword puzzles is reviewed, and the cognitive processing skills used when solving crossword puzzles is examined, based on a constructivist Information Processing model. Evidence from the literature reviewed shows that crossword puzzles must be relevant to the students' course material. Crossword puzzles based on the course content of the Scottish Higher Chemistry units Chemical Changes and Structure and Nature's Chemistry were compiled by the author and given to students as an aid to revision for Unit Assessments. Students were observed taking a detailed interest in reading course texts in order to find the solutions to the clues, and in anonymised feedback reported that the puzzles were fun to do, relevant and helpful in revision for assessments.

Key Words

Higher, Chemistry, Crossword, Puzzles, Thinking, Skills

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Introduction

Chemistry is now an established academic discipline with its own library of accumulated knowledge and vocabulary – chemical names, types of chemical reaction and so on. Students must learn, master and retain the language of chemistry (Markic and Childs, 2016), and thus it can be considered "powerful knowledge" (Young, 2009).

The "powerful knowledge" gains value when it is applied to solve problems – how to put together sometimes ill-fitting pieces of evidence to form a coherent picture, or to tackle higher level problems without a definitive answer (Wood, C. with Sleet, R, 1993). Problems differ in terms of the information available (input data) at the start (complete or incomplete); the method required to solve them may be familiar or unfamiliar, and the outcome may be given (a single, correct solution) or open (a number of possible solutions, all of which have advantages and disadvantages, with significant elements of judgment and compromise required by the enquirer). Table 1 below shows a classification of problems into Types, with increasing order of cognitive skill required to solve them (Wood, 2006). Problem Types 1 and 2 are the most common and simple type, with given (or complete) sets of input data (the question) and a given solution, arrived at by a familiar or unfamiliar method. Types 3 to 8 are the higher level types of problem more typical of scientific investigative skills (Wood, 2006). There is evidence that traditional forms of assessment in chemistry have tended to neglect the testing of problem-solving skills (Bennett, 2008).

In terms of the vocabulary of chemistry, there are two distinct categories of words. *Type 1* words, unique to chemistry, and *Type 2* words, which appear both in chemistry and general speech but with different meanings in each. Some examples are given in Table 2.:

Table 1 – Classification of Problems Based on Input Data, Method and Solution

Type	Input Data	Method	Outcome
1	**Complete**	**Familiar**	**Given**
2	**Complete**	**Unfamiliar**	**Given**

3	**Incomplete**	**Familiar**	**Given**
4	**Incomplete**	**Unfamiliar**	**Given**
5	**Complete**	**Familiar**	**Open**
6	**Complete**	**Unfamiliar**	**Open**
7	**Incomplete**	**Familiar**	**Open**
8	**Incomplete**	**Unfamiliar**	**Open**

Table 2 – Type 1 and Type 2 Words in Chemistry

Type 1 Words	**Meaning**	
Alkane	Hydrocarbon compound with no double or triple carbon to carbon bonding.	
Ester	Compound formed from reaction of alcohol with carboxylic acid.	

Exothermic	Reaction which gives out heat.	
Polymer	Large molecule built up of large numbers of individual units (monomers).	
Enthalpy	A thermodynamic function of state which may be considered as the “chemical potential energy” of a system.	
Type 2 Words	**Everyday Meaning(s)**	**Chemistry Meaning(s)**
Base	Headquarters, platform.	Source of electrons, chemical species which will neutralise an acid.
Period	Time interval, specific part of history.	Row in the Periodic Table of the Elements corresponding to the filling of an electron shell.

Reduce	Make smaller, make simpler.	Donate electrons, change to a lower oxidation state, combine with hydrogen, remove oxygen.
Saturated	Soaking wet, fully occupied.	Unable to undergo addition reactions, only substitution reactions because of a lack of carbon to carbon double or triple bonds; (of a solution) – unable to dissolve any more material.
Solution	The answer to a problem or question.	A homogeneous mixture with a solute distributed in a solvent (a dissolving medium).

In addition, many specific terms in chemistry look and sound similar: Sulfates and sulfites; alkanes, alkenes and alkynes; alkyl and acyl halides. All of these can present difficulties to students (Farrell and Seery, 2016).

Rote Learning *versus* Meaningful Learning

Ausubel (1963) drew a distinction between **rote** learning and **meaningful** learning in terms of the learner's cognitive system. When learning by rote, the incorporation of new knowledge is arbitrary and without a contextual relationship to existing knowledge. In contrast, meaningful learning integrates new and existing knowledge, and new meanings are constructed. Knowledge learned by rote is not easily applicable to new situations, and is therefore "situated" (Brown, Collins and Duguid, 1989).

However, this is not to say that rote learning of core material like chemical names and structures is of no value. It is as fundamental to learners of chemistry as the alphabet is to those learning to read and write. The application of this core knowledge to new situations (McCade, 2009) is essential for scientific progress.

According to Ausubel (1963), meaningful learning will occur if new knowledge is *connected* to existing knowledge, *relevant* to the learner, and *actively integrated* into the learner's mind so that new meanings may be constructed and reconstructed (Novak, 2002). Chemistry has a reputation as a difficult subject, with a perceived over-reliance on rote learning (Grove and Bretz, 2012). Learners place the greatest significance on the **relevance** of the course material; learners must choose to learn meaningfully by seeking connections between new and existing knowledge or will revert to rote learning, with the consequent risk that they will lose interest (Vedder-Weiss and Fortus, 2011).

Cognitive Skills

Bloom's Taxonomy (Bloom, 1956) ranks cognitive skills from low to high order. The lowest order cognitive skill is to **remember**, to accumulate core knowledge by rote learning. The third tier of the taxonomy, **application**, is associated with problem solving using existing knowledge, the 'transfer' skills (Mayer, 1998).

This approach has been applied to chemistry (Smith, 2016). Starting from a checklist of skills for the 'perfect' chemistry graduate, a taxonomy of skills was devised based on Bloom's work (Bloom, 1956). This identifies problem solving as a higher order skill than learning the fundamental core chemistry content, as shown in Table 3.

Table 3 – Taxonomy of Skills for Chemists (Smith, 2016)

Highest Order	Research and Creativity Skills	Project Planning and Execution	
	Team Working and Inclusivity	Oral Communication	Scientific

Literacy and Criticism	Independent Thinking		
Applied Chemistry	**Problem Solving**	Practical Skills	
Lowest Order	Chemistry Fundamentals		

It has been the author's experience that students at all levels from below National 5 to BSc (Scottish Credit and Qualifications Framework (SCQF) Levels 4 to 7) are much more able to recall learned facts than to apply knowledge to solve problems. This has been found to be the case in chemistry (Bodner, 2003; Tsaparlis and Zoller, 2003) and in other fields, indicating a need to teach problem-solving skills in a way which is both relevant to the students' area of study and which stimulates their interest. This represents a significant and continuing challenge to the teaching of science (Kaptan and Timurlenk, 2012). Students learn more deeply when they are interested in what they are doing (Dewey, 1913), and they are more likely to be interested if a teaching method combines relevance to their learning (Ausubel, 1963) and an element of novelty (Yuriev, Capuano and Short 2016).

This led to the decision to use some kind of game or puzzles as a teaching tool. Educational games and puzzles are a fun way to engage the enthusiasm of students, facilitate active learning, enhance problem-solving skills and encourage small-group discussion so that class-learned concepts and ideas are reinforced (Bailey, Hsu and DiCarlo, 1999). Because of the additional need to develop mastery of the chemical vocabulary, crossword puzzles (with solutions being chemical words of both Types 1 and 2) were selected for this project.

Crossword Puzzles as a Teaching Tool in Chemistry and Other Disciplines

Crossword puzzles have been used as teaching tools in a range of academic disciplines, including chemistry (Joag, 2014; Harris, 1986; Cady, 2012; Parker, 1980), pathology (Saxena *et al.,* 2009), pharmacology (Gaikwad and Tankhiwale,2012), psychology

(Crossman and Crossman, 1983), medicine (Shah, Lynch and Macias-Moriarty, 2010) economics (Lin and Dunphy, 2013), nursing (Raines, 2010) and in business studies (Jaramillo, Losada and Fekula, 2012).

The use of crossword puzzles in the teaching of Chemistry was the subject of a recent review (Yuriev, Capuano and Short, 2016). Students reported that crossword puzzles make learning fun, aid revision, help with learning academic vocabulary and improve performance in summative assessments. Students understand science on a much deeper level when they have to get involved with questions to solve problems, rather than sit listening passively as answers are given (Waldrop, 2015).

Mental Processes Involved in Solving Crossword Puzzles

The pursuit of scientific knowledge is constructivist: using existing knowledge and the work of others to construct meaning from new observations. Ausubel's model (Ausubel, 1963) is constructivist, in that it involves the construction of new knowledge through synthesis with existing knowledge, but it is narrow in its focus. It helps the learner to make sense of new information, but only within the well-defined parameters of an established academic discipline. The learners, in this case the Higher (SCQF Level 6) Chemistry class, are not setting the agenda for their own learning – that is already set in the course syllabus for the Higher Qualification – the "powerful knowledge" (Young, 2009). However, the gradual development of higher level cognitive skills in relation to this narrow field of study will be of genuine benefit to the students in later life (Page, 2013).

The memory processes involved in solving crossword puzzles have been studied (Huit, 2003; Yuriev, Capuano and Short, 2016) and an **Information Processing** model based on a combination of sensory, working and long term memory devised (Roberts and Rosnov, 2006; Proctor and Vu, 2012), as shown in Figure 2.

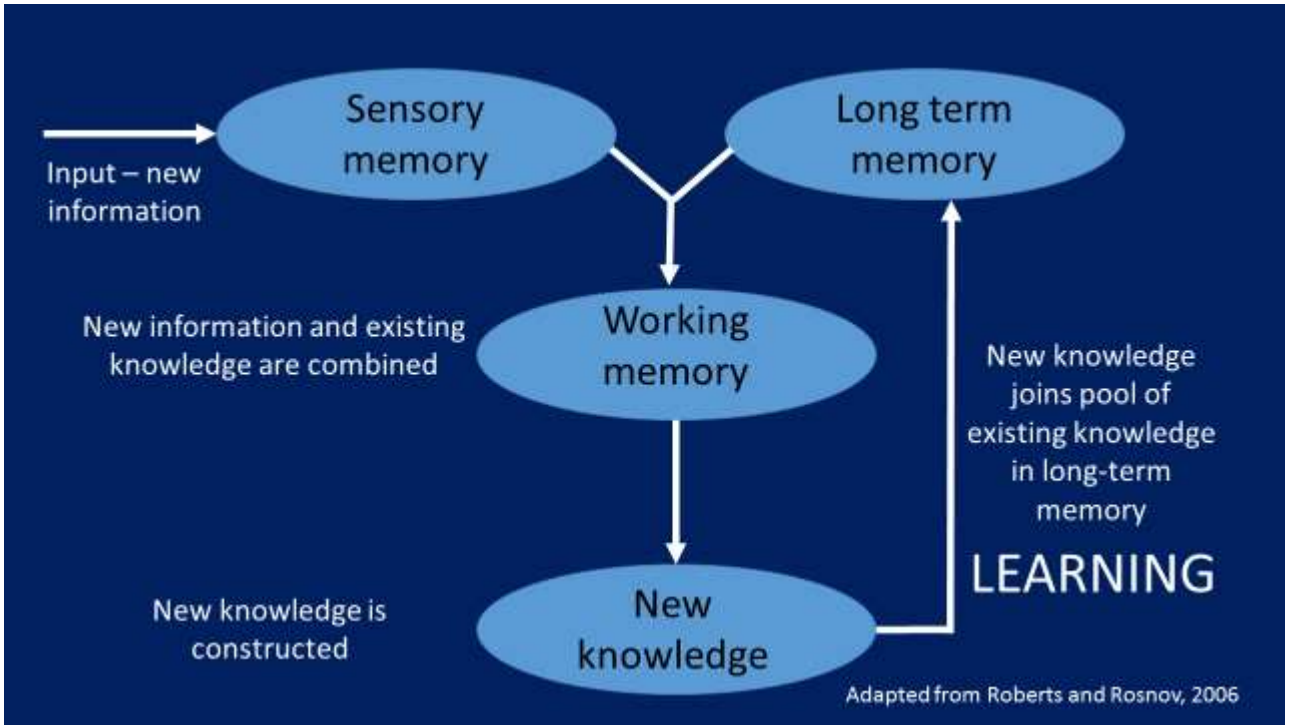

Figure 2 – Memory Processes in Problem-Solving (adapted from Roberts and Rosnov, 2006)

Sensory memory ('receipt memory') is responsible for receiving new information in the form of stimuli – sight (iconic memory), sound (acoustic memory), touch (tactile memory). Long term memory ('storage memory') is the reservoir for the storage of already-learned information. Working memory ('construction memory') is the memory space where the new and stored information are actively combined by the learner and new meanings constructed. The learner is NOT merely a passive processor of information. In this respect, Information Processing may be considered to be constructivist (Raines, 2010).

Applying this model to crossword puzzles, students synthesise the sensory memory information of the clue with stored knowledge recalled from the long term memory to solve the clue using working memory. Higher levels of mental activity are used,

particularly if the clues have a cryptic element. These mental processes include analysis of the partial information presented in the clue, selection of stored information from long term memory, and synthesis of these two to construct new knowledge and arrive at the solution.. In a study of crossword puzzles in chemistry this model is termed Information Processing (Yuriev, Capuano and Short, 2016) but, in its use of existing knowledge to make new knowledge it is, in reality, constructivist. This term is explicitly used in a study of crossword puzzles used for the training of student nurses (Raines, 2010). The mind is not merely an information processor but a constructor of new knowledge of value to the individual learner (Bruner, 1990)

Schraw and co-workers (Schraw, Crippen and Hartley, 2006) picture problem-solving as a three-stage constructive process. Learners are given incomplete pieces of information which may result in more than one possible solution. Students must select and evaluate solutions (cognition) and constantly think about and re-evaluate their way of thinking (metacognition). The initial solution may FAIL, requiring the student to go back and try again, requiring a degree of persistence and willingness (motivation). All required for self-regulated learning, and opportunities for all of these are presented by educational puzzles. Cryptic clues used in many crossword puzzles work like this, solutions may not be immediately obvious, and a degree of active thinking, trying out (and possibly rejecting) different possible solutions are necessary before arriving at the solution.

Setting and Compiling Higher Chemistry Crossword Puzzles

It was essential that the puzzles were relevant to the course material being studied (Ausubel, 1963) so that students assigned importance to it. This meant close relevance to the concepts and terminology prescribed in the Higher Chemistry Course Specification (SQA, 2014).

Two puzzles were set, one each based on the course material for Higher Chemistry (SQA, 2016) Units 1 and 2, and as included in the text book used by the students to accompany the course (Anderson, Allan and Harris, 2012). These Units were being studied by the class at the point in the semester when the puzzles were introduced. Since the completion of the activity described in this essay, modifications were made to the assessment of the Higher Chemistry course without making any changes to the course content; the Units were reclassified as “areas of chemistry” (SQA, 2018).

Unit 1, Chemical Changes and Structure, covered the following key areas:

- Controlling the Rate of Reaction
- The Periodic Table: Bonding and Structure
- Trends in the Periodic Table, and
- Bonding in Compounds

Unit 2, Nature's Chemistry, covered:

- Alcohols, Carboxylic Acids and Esters
- Fats, Oils and Soaps
- Proteins
- The Chemistry of Cooking and Oxidation of Food
- Fragrances, and
- Skin Care

Setting the Clues

Clues were composed and set by the author with a range of complexity, from simple "word recall" to newspaper-style cryptic clues, including use of anagrams. Following each clue, the number of letters in the solution was given in brackets. Where the solution consisted of more than one word, the number of letters in each of the words was given, for example6, 6 for "alkali metals". Examples of clues are set out in Table 4.

Table 4 – Examples of Crossword Clue Types Used in this Crossword Puzzle Exercise

Type of Clue	Clue	Solution	Explanatory Notes

Simple Word Recall	"Ester of glycerol and saturated fatty acids (3)"	FAT	No decoding of the clue is necessary. The solution is unambiguous and based on recall of learned information.
Cryptic Non-Anagram	"3, 11, 19, 37, 55 and 87 (6, 6)"	ALKALI METALS	The clue sets out the Atomic Numbers of the alkali metals in the Periodic Table of the Elements. To solve the clue students must study the Table to find out that the elements with these numbers all occur in the same column (Group).
Cryptic Anagram	"You must transform something to make fat or oil, e.g. dirty relic (12, anagram)"	TRIGLYCERIDE	The clue tells the student that the solution has 12 letters and an anagram of part of the clue. This is reinforced by the word "transform" in the clue. The terms "fat" and "oil" point the student towards the relevant chapters of the Higher text book. The solution is a chemical term for fats and oils, and is an anagram of "e.g. dirty relic".

The full sets of clues for the puzzles, including solutions, are attached as **Appendix 1** and **Appendix 2**. Having composed the clues, the crossword puzzles were set as grids using a free online puzzle compiler (armoredpenguin, 2016). The Higher Chemistry Unit 1 and Unit 2 puzzles are attached as **Appendix 3** and **Appendix 4**.

Introducing the Higher Chemistry Students to the Crossword Puzzles

Students were given the puzzles at the start of a revision period and encouraged to work together. Access to the core text book, notes and online sources of information was encouraged, but no assistance was given to the students by the lecturer.

The effect on the class of the introduction of the puzzles was striking. When the revision session started, noticeable changes occurred quickly. Students formed into groups and began working together and assisting each other to solve the clues. There was a constant buzz of conversation, and the sound of books and notes being leafed through, backwards and forwards, to find information to solve the clues. Previous revision sessions were typically quiet, with students working individually with their notes and text books for the first 15 minutes or so. They would appear to lose interest and put away their books and notes and pick up their mobile phones, or else become distant or distracted.

Obtaining Student Feedback

Feedback was sought from the class using an anonymous form as set out in Figure 3. The form incorporates eight statements concerning the puzzles, answerable by selecting one answer from five, ranging from "strongly agree" to "strongly disagree". An additional box for written comments was also provided.

Statement	**Strongly Agree**	**Agree**	**Neither Agree Nor Disagree**	**Disagree**	**Strongly Disagree**
The crossword puzzles were fun to do					
The crossword puzzles made me look at my notes and textbook more thoroughly					
The crossword puzzles helped me to understand the course material					
The crossword puzzles were relevant to the course					

The crossword puzzles helped me to understand chemical terms better					
Doing the crossword puzzles has helped me to solve chemistry problems					
Doing the crossword puzzles has helped me to revise for assessment better					
The crossword puzzles made it easier for me to learn the course materials					
Any Other Comments					

Figure 3 – Anonymous Feedback Form Used

A numerical value was assigned to each of the five answers as shown in Figure 4:

Strongly Agree	+2
Agree	+1
Neither Agree nor Disagree	0
Disagree	-1
Strongly Disagree	-2

Figure 4 – Numerical Values Attached to Answers in the Anonymised Feedback Form

Positive feedback would generate a positive number, negative feedback a negative number. The numerical value assigned to each answer was awarded every time the answer was given.

Results of Student Feedback

The total number of responses and scores are shown in Table 5:

Table 5 – Feedback Responses from Higher Chemistry Students to The Crossword Puzzle Exercise

Statement Class Size = 14	**Strongly Agree (+2)**	**Agree (+1)**	**Neither Agree Nor Disagree (0)**	**Disagree** (-1)	**Strongly Disagree (-2)**
The crossword puzzles were fun to do +24	**10**	**4**	**0**	**0**	**0**
The crossword puzzles made me look at my notes and textbook more thoroughly +18	**7**	**4**	**1**	**0**	**0**
The crossword puzzles helped me to understand the course material +20	**9**	**2**	**2**	**0**	**0**
The crossword puzzles were relevant to the course +26	**12**	**2**	**0**	**0**	**0**
The crossword puzzles helped me to understand chemical terms better +19	**7**	**5**	**2**	**0**	**0**

Doing the crossword puzzles has helped me to solve chemistry problems +16	**5**	**6**	**3**	**0**	**0**
Doing the crossword puzzles has helped me to revise for assessment better +20	**9**	**2**	**3**	**0**	**0**
The crossword puzzles made it easier for me to learn the course materials +18	**7**	**4**	**3**	**0**	**0**

No explicitly negative responses ("disagree" or "strongly disagree") were given, with the most negative responses expressed being "neither agree nor disagree". This response was in the minority for all the eight statements in the feedback form.

The strongest agreement was for the puzzles being, "relevant to the course" (+26) and "fun to do" (+24). There was good agreement that puzzles, "help with understanding of course material" (+20) and "help students to revise better for assessments" (+20). The lowest overall score, for the puzzles, "helping in the solving of chemistry problems", was still +16, indicating a good degree of agreement.

In addition to the tick box responses above, written and verbal feedback was received from the students as follows:

Bringing crossword puzzles to the class as an additional learning and revision tool for the Higher Chemistry class thus appeared to have been successful. Revision changed from a near-silent, solitary, short duration activity to a lively, noisy, group activity – a real community of practice (Wenger, 2011). Students worked together enthusiastically and supported each other, exchanging clue solving strategies and tips. Deep examination of the textbook and lecture notes became the norm, as the students sought to complete the puzzles.

It is appropriate at this point to add notes of caution. The enthusiasm shown by the students for the puzzles may have been due to a "novelty" effect, which would exaggerate the actual educational value of the puzzles; in addition, if the puzzles were to be used too often there is the danger that students would become great puzzle solvers and not great chemists; accordingly, in future the

puzzles will be used sparingly, predominantly as an additional learning tool to add variety when revising for assessments but not at other times during the course.

Conclusion

This was a positive first use of Higher Chemistry crossword puzzles, and will be used, though sparingly, in future Higher Chemistry classes. Crossword puzzles may be prepared easily for chemistry classes at levels other than Higher, and indeed for other science classes such as biochemistry, in fact any problem-solving based discipline with a distinct vocabulary which must be mastered. This will be done with the caveat that it will be used occasionally in order to ensure that students do not become merely good crossword solvers – the object is to ensure that they become good *scientists*.

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Appendix 1: Crossword Clues – Chemical Changes and Structure

Higher Chemistry Unit 1 Chemical Changes and Structure

Clue	**Solution**	**Letters**
High-born gas.	NOBLE	5
Enclave transforms into outer electron shell.	VALENCE	7 (anagram)
Charged atom? I'm positive!	CATION	6

Charged atom? Negative!	ANION	5
Time taken to get across a Row of the Table.	PERIOD	6
Dispersion Forces are active in this big city.	LONDON	6
Elements in the same Column form a gang.	GROUP	5
9, 17, 35, 53, 85 and 117	HALOGENS	8
3, 11, 19, 37, 55 and 87	ALKALI METALS	6, 6
Clue about a form of carbon is very, very hard.	DIAMOND	7
I made things go faster, but I'm just the same now as I was before I started. What am I?	CATALYST	8
Transform nice kit into energy of motion.	KINETIC	7 (anagram)
No charge for this sub-atomic particle.	NEUTRON	7

To make a word for chemical potential energy, change then play.	ENTHALPY	8 (anagram)
H_2, N_2, O_2, F_2, Cl_2, Br_2, I_2 – get this type of molecule by changing mac, idiot!	DIATOMIC	8 (anagram)
Not tied to one area – like electrons in metals?	DELOCALISED	11
The most reactive of them all!	FLUORINE	8
Bonds where electrons are shared unequally – look for them in the Arctic or Antarctic.	POLAR	5
Cations and anions – what holds us together?	IONIC BONDING	5, 7
This form of carbon isn't lead, but it is in your pencil!	GRAPHITE	8
What kind of structures are diamond, graphite and silicon? To find the answer look around Town Centre Val. OK?	COVALENT NETWORK	8, 7 (anagram)
Forces between atoms and molecules – something vandals wear.	VAN DER WAALS	3, 3, 5 (anagram)

Noble gases live the single life.	MONATOMIC	9
Spandex does what water does when it freezes!	EXPANDS	7 (anagram)
Difference in electronegativity between two atoms makes everlasting one of these.	PERMANENT DIPOLE	9, 6
8 atoms form a crown in this flowery yellow element.	SULFUR	6
Knocking an electron off an atom – or the Energy required to do the same?	IONISATION	10
Searching for a word meaning a reaction which absorbs heat? Examine The Micro End.	ENDOTHERMIC	11 (anagram)
Reaction gave out heat, blowing up the ox – crime!	EXOTHERMIC	10 (anagram)
This element has a covalent network structure, but is it broon?	BORON	5 (anagram)

Cations and anions are arranged in a three-dimensional structure which could be tactile.	LATTICE	7 (anagram)

Appendix 2: Crossword Clues – Nature's Chemistry

Clue	**Solution**	**Letters**
My proper name is propane-1,2,3-triol.	GLYCEROL	8
Ester of glycerol and saturated fatty acids.	FAT	3
Ester of glycerol and unsaturated fatty acids.	OIL	3
It's the first step towards a free radical chain reaction.	INITIATION	10
Two free radicals meet and get together – The End.	TERMINATION	11
Solid fat sounds like it's soaking wet!	SATURATED	9
Alcohol and carboxylic acid get together to make sweet smell.	ESTER	5

Oil and water won't mix until one of these gets to work.	EMULSIFIER	10
This kind of alcohol will oxidise….. twice!	PRIMARY	7
Make essential oil molecule from Pen Tree.	TERPENE	7 (anagram)
Who can change things round to make a terpene building block? I, Penrose.	ISOPRENE	8 (anagram)
Eastenders, Coronation Street, sodium salts of long chain carboxylic acids….	SOAPS	5
Oil or amino acid: we sound like you can't do without us!	ESSENTIAL	9
When we get together we make proteins.	AMINO ACIDS	5, 5
Use positive test with Tollens' reagent to check your reflection.	SILVER MIRROR	6, 6
Look in basket one time to find an oxidation product of an alcohol.	KETONE	6
You must transform something to make fat or oil, e.g. dirty relic.	TRIGLYCERIDE	12 (anagram)

A molecule which has a strong flavour and odour is likely to be this: v. late oil!	VOLATILE	8 (anagram)
Find link between amino acid molecules by rummaging round deep pit.	PEPTIDE	7 (anagram)
Does reaction between alcohol and carboxylic acid result in water droplets forming on the windows?	CONDENSATION	12
Tablets of this ester are a powerful painkiller – swallow in pairs.	ASPIRIN	7 (anagram)
Soap molecule tail sounds like it's afraid of water.	HYDROPHOBIC	11
Halfway between Primary Alcohol and Carboxylic Acid.	ALDEHYDE	8
Hard water stops soap working, so who do we need? Ted Regent, possibly!	DETERGENT	9 (anagram)
Fibrous protein extracted from clean log.	COLLAGEN	8 (anagram)
Where there's alcohol, you'll ALWAYS find this group!	HYDROXYL	8

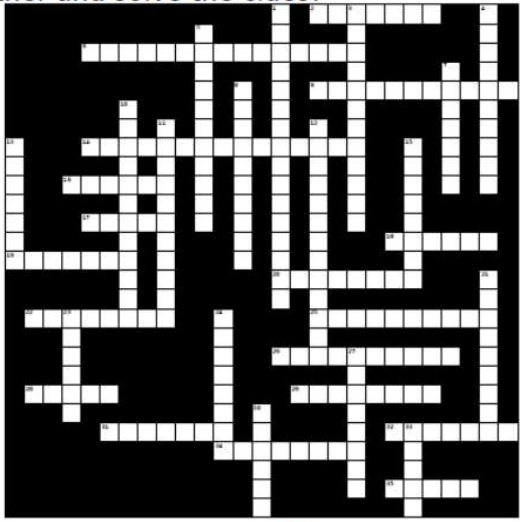
This class of alcohol won't oxidise: irate, try doing something different!	TERTIARY	8 (anagram)
Want to know the functional group of aldehydes and ketones? Ask Bony Carl.	CARBONYL	8 (anagram)
The first one (Greek) of the protein secondary structures gets itself in a twist!	ALPHA HELIX	5, 5
These are added to food to stop it going off, so after eating, I stand a toxin.	ANTIOXIDANTS	12 (anagram)

Appendix 3: Crossword Puzzle Higher Chemistry Unit 1

HIGHER CHEMISTRY UNIT 1

Dr. Anthony Luke

A crossword puzzle to help you revise Unit 1 - Chemical Changes and Structure. Some clues are easy-peasy, some are harder, and some are fiendish! Work together and solve the clues!



Across

2 Clue about a form of carbon is very, very hard (7)
6 What kind of structures are diamond, graphite and silicon? To find the answer, rebuild Town Centre Val, OK? (8, 7, anagram)
9 Not tied to one area, like electrons in metals? (11)
14 Difference in electronegativity between two atoms in a bond makes one of these (9, 6)
16 Time taken to get across a row of the Table (6)
17 Bonds where electrons are shared unequally - look for them in the Arctic or Antarctic (5)
18 Eight atoms in a crown in this flowery yellow element (6)
19 Spandex has what it takes to do what water does when it freezes! (7, anagram)
20 This form of carbon isn't lead, but it is in your pencil! (8)
22 9, 17, 35, 53, 85 and 117 (8)
25 Knocking an electron off an atom, or the Energy required to do the same? (10)
26 I'm a cation, you're an anion. We're opposites, so what holds us together? (5, 5)
28 Elements in the same Column form a band (5)
29 H2, N2, O2, F2, Cl, Br2, I2 - get this type of molecule by changing mac, idiot! (8, anagram)
31 No charge for this sub-atomic particle (7)
32 Enclave transforms into outer electron shell (7, anagram)
34 To make a word for chemical potential energy, change then play (8, anagram)
35 This element has a covalent network structure, but is it broon? (5, anagram)

Down

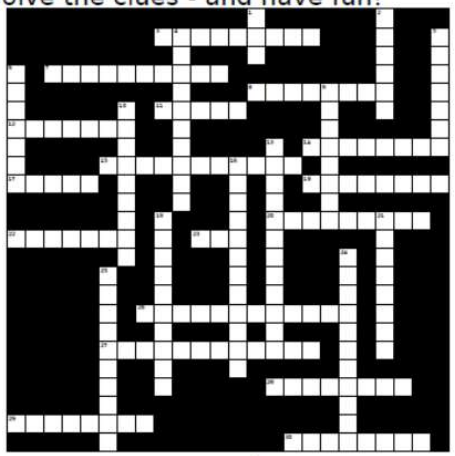
1 Chemical reactions (and us!) need this to get going (10, 6)
3 3, 11, 19, 37, 55 and 87 (6, 6)
4 Royal elements don't mix with the riff-raff from the other parts of the Table! (5, 5)
5 Searching for a reaction which absorbs heat? Examine The Micro End (11, anagram)
7 Transform nice kit into energy of motion (7, anagram)
8 Reaction gave out heat, blowing up the ox : crime! (10, anagram)
10 As this gets smaller, the rate gets..... FASTER??? (8, 4)
11 Forces between atoms and molecules - like something vandals wear (3, 3, 5, anagram)
12 This affects the rate of a reaction. To work out the answer, you need to think hard! (13)
13 Cations and anions are arranged in a 3-D structure which could be tactile (7, anagram)
15 To increase the rate of a reaction involving gases, try some ..... squash? (8)
21 Noble gases live the single life! (9)
23 Dispersion Forces active in this big city (6)
24 The most reactive of them all (8)
27 I made things go faster, but I'm just the same now as I was before I started (8)
30 Charged atom? I'm positive! (6)
33 Charged atom? Negative! (5)

Appendix 4: Crossword Puzzle Higher Chemistry Unit 2

HIGHER CHEMISTRY UNIT 2

Dr. Anthony Luke

A crossword puzzle to help you revise Unit 2 - Nature's Chemistry. Some clues are simps, others more tricky, and some of them are stinkers! Work together to solve the clues - and have fun!



Across

3 Solid fat sounds like it's soaking wet! (9)
7 It's the first step towards a free radical chain reaction (10)
8 Fibrous protein extracted from clean log (8, anagram)
11 EastEnders, Coronation Street, sodium salts of long chain carboxylic acids ... (5)
12 Find link between amino acids by rummaging around deep pit (7, anagram)
14 This class of alcohol won't oxidise: irate, try doing something different! (8, anagram)
15 Two free radicals meet and form a stable molecule - The End (11)
17 Alcohol and carboxylic acid get together and make sweet perfume! (5)
18 Where there's alcohol, you'll ALWAYS find this group! (8)
20 Oil or amino acid - we sound like you can't do without us. (9)
22 Tablets of this ester are a powerful painkiller - swallow in pairs (7, anagram)
23 Ester of glycerol and unsaturated fatty acids (3)
26 Use positive test with Tollens' reagent to check your reflection (6, 6)
27 These are added to food to stop it going off - so, possibly, I stand a toxin (12, anagram)
28 Want to know the functional group of aldehydes and ketones? Ask Bony Carl (8, anagram)
29 A molecule which has a strong flavour and odour is likely to be this: v. late oil! (8, anagram)
30 My proper name is propane-1,2,3-triol (8)

Down

1 Ester of glycerol and saturated fatty acids (3)
2 Look in basket one time to find an oxidation product of an alcohol (6)
4 When we get together we make proteins (5, 5)
5 This kind of alcohol will oxidise - twice! (7)
6 Make essential oil molecule from Pen Tree (7, anagram)
9 Halfway between Primary Alcohol and Carboxylic Acid (8)
10 Hard water stops soap working, so who do we need? Ted Regent, possibly! (9, anagram)
13 Does reaction between alcohol and carboxylic acid result in water droplets forming on the windows? (12)
16 You must transform something to make fat or oil, e.g. dirty relic (12, anagram)
19 Oil and water won't mix until one of these gets to work (10)
21 Who can change things round to make a terpene building block? I, Penrose. (8, anagram)
24 Soap molecule tail sounds like it's afraid of water (11)
25 The first one (Greek) of the protein secondary structures gets itself in a twist! (5,5)