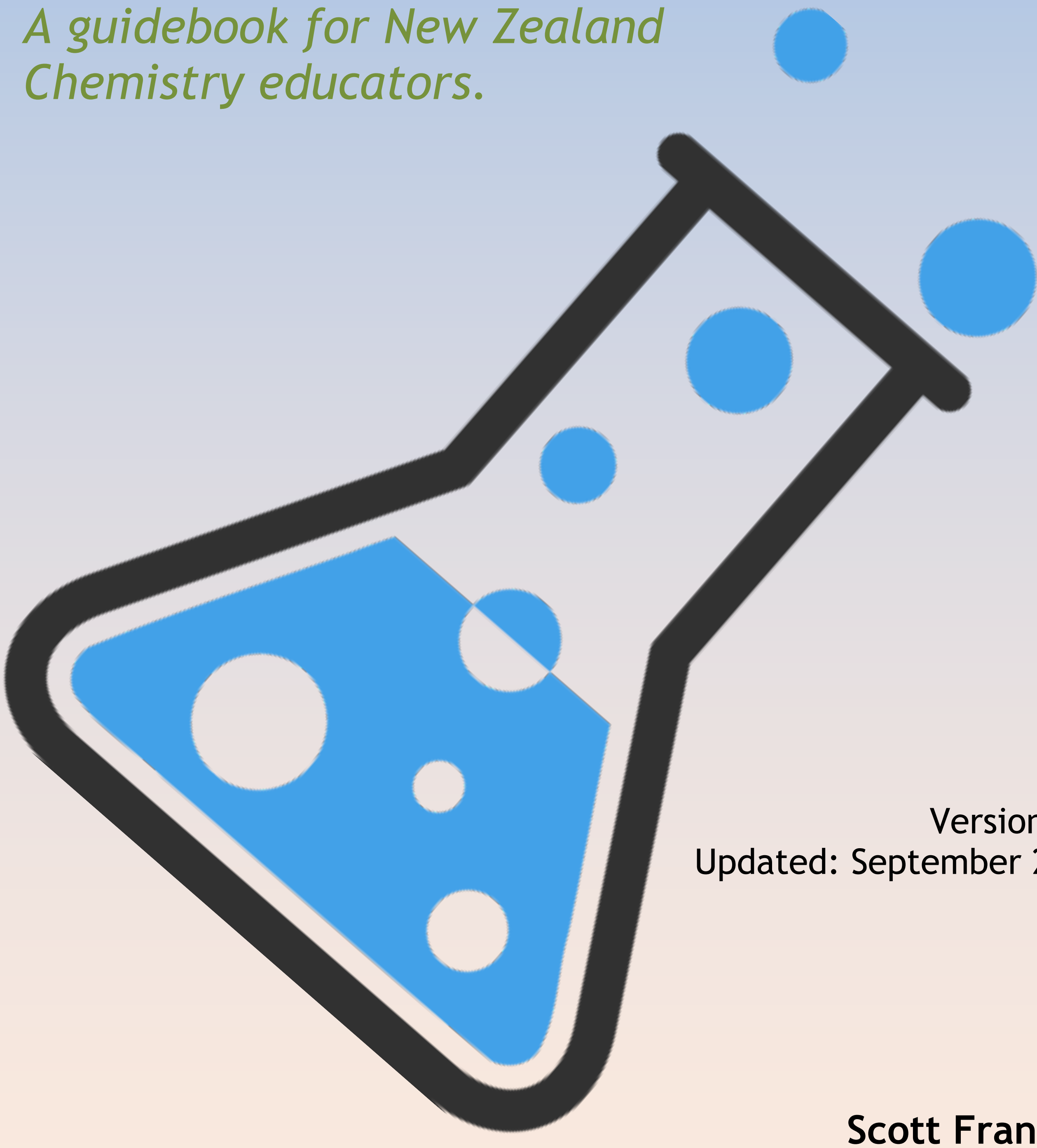
Scholarship Chemistry 101

A guidebook for New Zealand Chemistry educators.



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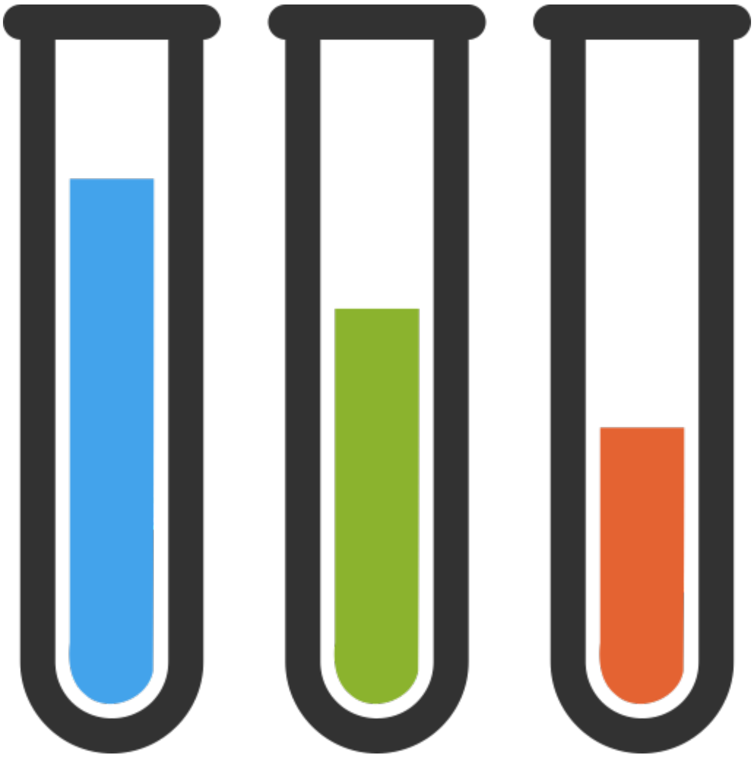

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1. Introduction

Scholarship Chemistry is one of the best parts of high school chemistry, and I believe that any student who is capable should be given the opportunity to prepare for it. The goal of this booklet is to aid chemistry teachers in becoming more knowledgeable of the expectations of the Scholarship examination and to provide ideas on how best to support students in engaging with preparation for it. I have spent many years guiding and supporting Scholarship students, I really enjoy working with students on this kind of chemistry, and I wish for all who read this document to feel supported and confident to be able to do the same.

Preparing students for Scholarship is a process that ideally should start in Year 9 and be a focus of teachers throughout their students' education. Students with obvious scientific and mathematical capabilities should continue to be extended throughout their learning pathway at secondary level so by the time they reach Year 13 problem solving has become second nature.

Scholarship students must become greatly proficient at Year 12 and Year 13 chemistry as a baseline expectation. Students who have gaps in their understanding, or an inability to recall particular properties and reactions of substances, will ultimately struggle to achieve in Scholarship.

Scholarship Chemistry assesses students' ability to think critically and solve abstract problems using the knowledge they have gained studying chemistry. Many of the problems featured in Scholarship Chemistry involve a significantly higher degree of complexity than they will ever experience in standard Level 3 assessments. Some problems will bring together different ideas from multiple topics that are traditionally taught as segregated parts of the chemistry curriculum. Students must be able to approach questions of significant difficulty and be able to find a way to not only solve the challenge posed in the question, but also provide a coherent, scientifically accurate answer to account for the observations or changes occurring.

Scholarship students are the kind of students who are able to approach difficult problems with an interest and curiosity in solving the solution using well-communicated ideas. Students who find they "hit a wall" when facing tough questions will be unlikely to eventually complete enough of the examination questions to be able to achieve in it. Only through perseverance, practice, and understanding will they be able to make the progress needed to succeed.

To build these skills, students aspiring to achieve in Scholarship should be provided with opportunities to attempt difficult chemistry problems and problem solving tasks throughout their Year 13. They ideally will engage in answering a range of questions for every key topic area in Year 12 and 13 chemistry. Past Scholarship examinations and those produced by NZIC are ideal for this. These can be completed independently but students will normally benefit from completing these tasks in a tutorial environment with trained chemistry teachers. Starting students down the track of developing problem solving skills in Year 12 with the Chemistry Olympiad is a great starting point; you can find more detail on this further on in this document.

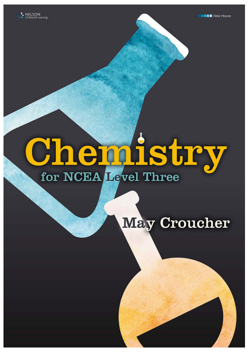
I have provided in this document a table of extension content I personally like to explore with students that goes beyond their standard Level 3 curriculum. While this content will not be assessed in Scholarship examinations, due to the fact that the examination only draws questions from Level 7 and 8 of the New Zealand Curriculum, the thinking skills developed in understanding these extension topics provide additional understanding which will support Scholarship achievement – particularly in areas of extrapolation and reflection.

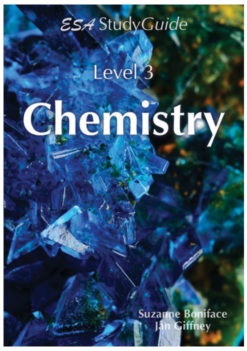
Resources students should access for Scholarship level preparation include:

- Classroom Workbooks
- Web-based resources such as NoBrainTooSmall.co.nz and BestChoice.net.nz
- Any UK A-Level Textbook – See section 10 for recommended text.
- Past Scholarship Exams - Top Scholar, Questions, Answers, Examiner Reports
- ChemGuide.co.uk

I personally highly recommend the following texts:

- Chemistry for NCEA Level Three; M Croucher; Nelson Cengage Learning
- Advanced Chemistry Textbook; M Clugston, R Flemming; Oxford University Press
- ESA Study Guide - Year 13 Chemistry; S Boniface, J Giffney; ESA Publications
- Scholarship Year 13 Chemistry Workbook; J Giffney; ESA Publications





In addition to studying these resources students should be fully aware of the *Quantities, Units, Symbols and Nomenclature* guidelines provided on the NZQA website. Deficiencies in being able to communicate data and concepts using appropriate terminology and units will limit success for students.

Feedback and comments on this guidebook for the development of future versions will always be appreciated.

- Scott

2. The Scholarship Performance Standard

The Scholarship Performance Standard, provided by the Ministry of Education, lists the defining differences between a Scholarship outcome and an Outstanding Scholarship outcome for students in this exam. Communication, problem solving, critical thinking, abstract reasoning, and accurate knowledge are the defining criteria in the different levels of achievement. See diagram 1 below.

Outcome Description

The student will use knowledge of chemistry to demonstrate the ability to integrate and apply chemical principles and skills to a wide range of situations, to analyse problems from a chemical perspective and present coherent and well-reasoned answers.

Scholarship Performance Descriptor

The student will demonstrate aspects of high level:

- analysis and critical thinking
- integration, synthesis, and application of highly developed knowledge, skills, and understanding to complex situations
- logical development, precision and clarity of ideas.

Outstanding Performance Descriptor

In addition to the requirements for Scholarship, the student will also demonstrate, in a sustained manner, aspects of:

- perception and insight
- sophisticated integration and abstraction
- independent reflection and extrapolation
- convincing communication.

Subject specific definitions:

- *Analysis and critical thinking* involves making well reasoned, justified judgements in the application of chemical principles in contexts that may be unfamiliar.
- *Integration, synthesis and application of highly developed knowledge, skills and understanding to complex situations* involves selecting, organising, and applying relevant chemical concepts and principles to solve problems in a chemistry context.
- *Logical development, precision and clarity of ideas* involves organising, planning and developing a coherent discussion or explanation for given observations or chemical phenomena, using appropriate chemical symbols and terms. This may include sources of error, reliability of data collected and validity of conclusions drawn in relation to practical work.
- *Sophisticated integration and abstraction* involves planning, processing, linking, and applying chemical principles across all areas of chemistry to solve problems or provide explanations of observations from a chemical perspective.
- *Independent reflection and extrapolation* involves identification and analysis of information from both material provided and the student's own knowledge to analyse problems from a chemical perspective.
- *Convincing communication* involves planning and presenting a fully integrated, fluent, coherent, and relevant discussion.

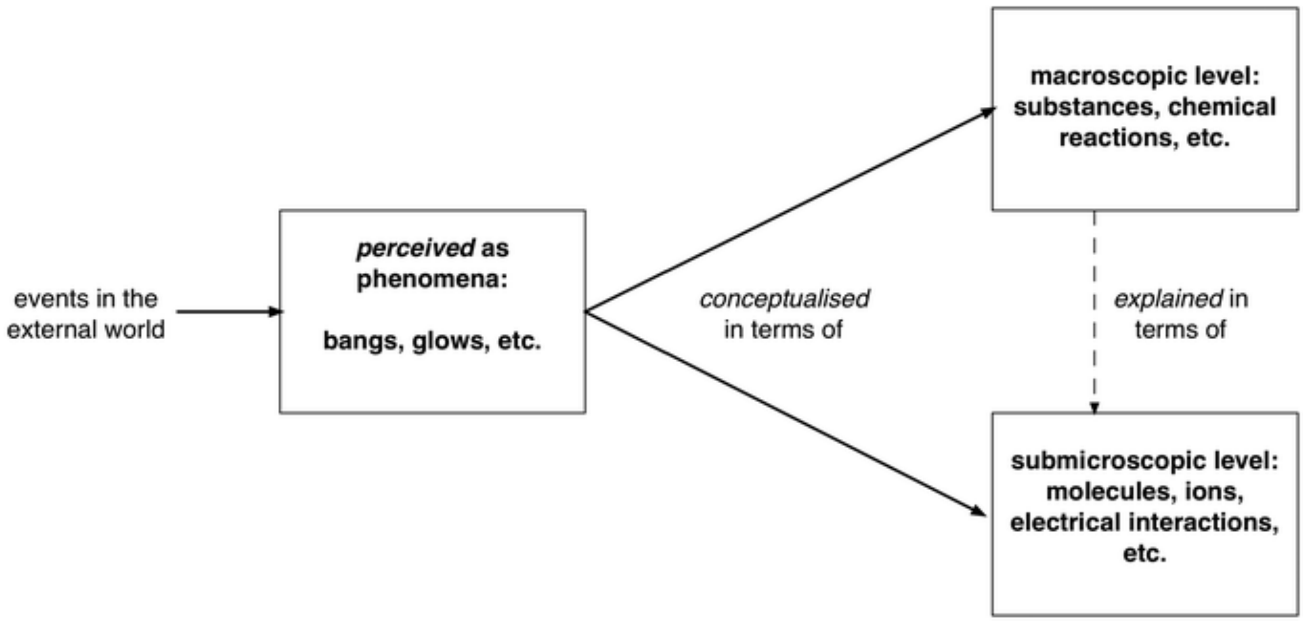


Diagram 1 – Conceptualisation of chemical events (Taber, 2013)

3. The Examination

The topics, scope, length and style of Scholarship questions vary significantly year-to-year. This mimics real-world chemistry that very rarely falls into distinct categories as students experience it during secondary school. Students are best prepared for coping with this when they understand and anticipate the high complexity and are willing to give any kind of question a shot.

Some questions can provide little detail in what students are expected to do, but still require them to produce concise explanations of their chemical understanding. For example, this question from the 2011 exam:

QUESTION ONE

(a) (i) Discuss how the charges on subatomic particles contribute to the size of atoms and their ions.

Some questions may instead contain significant amounts of information that the students must read, process, and understand before writing logical, precise answers. For example, this question from the 2012 exam:

(b) The amount of carbon dioxide in the atmosphere is increasing due to the combustion of fossil fuels. The concentration of a dissolved gas in a solution is directly proportional to the partial pressure of that gas above the solution. This means that increasing the carbon dioxide in the Earth's atmosphere will increase the amount of dissolved carbon dioxide in the oceans. The concentration of carbonate ions, utilised by shell-forming organisms to form $CaCO_3$, varies with the amount of dissolved CO_2. This, in turn, affects the availability of dissolved calcium ions.

Information

- $CO_2(g) \rightleftharpoons CO_2(aq)$
- Solubility of CO_2 in water obeys Henry's Law: $\dfrac{[CO_2(aq)]}{P_{CO_2}} = K_h$, where P_{CO_2} is the partial pressure of CO_2 in the atmosphere.
- Henry's Law constant for CO_2 at 25°C, is 3.317×10^{-4} mol L^{-1} kPa^{-1}.
- The current partial pressure of CO_2 in the atmosphere is 0.0397 kPa.
- Dissolved carbon dioxide reacts with the water to form carbonic acid:
  $CO_2(aq) + H_2O(\ell) \rightleftharpoons H_2CO_3(aq) \quad K_1 = 1.70 \times 10^{-3}$
- H_2CO_3 is a weak acid: $H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+ \quad K_2 = 2.51 \times 10^{-4}$
- HCO_3^- also reacts with water: $HCO_3^- + H_2O \rightleftharpoons CO_3^{2-} + H_3O^+ \quad K_3 = 5.62 \times 10^{-11}$
- $CaCO_3$ is a sparingly soluble salt $\quad K_s = 4.8 \times 10^{-9}$
- The pH of the oceans is currently about 8.10.

Calculate the concentration of Ca^{2+} ions at the current pH of the ocean, using the data given above.

Another aspect to be aware of is that different kinds of questions can vary in difficulty depending on the different amounts of information provided, different degrees of familiarity that students have with the concepts/questions, and the different levels of clarity in the expected answer. Some questions may be very open ended and leave it up to the students to determine the answers. Students should expect to face greater amounts of complexity, unfamiliarity and vagueness than in Level 3; at this point "scaffolding" ceases to feature in many questions.

For example, this part of a question from the 2014 examination:

> Discuss the similarities, differences, and trends in the intermolecular forces **documented in the graph** for the substances given. (Assume that the inter-particle forces between the argon atoms come into the category of intermolecular forces.)

Students who have faced a variety of Scholarship style problems are better prepared than those who simply study problems at Level 3 NCEA. In fact, students and teachers who only ever study up to Level 3 NCEA questions, even at an Excellence level, may find the switch to the style of questions found in Scholarship Chemistry to be an overwhelming, daunting and entirely impossible task to cope with.

In the table below are eight different varieties of problems that can exist, as well as a description of the relative level of difficulty they will cause students. Ideally students should only be considered "prepared" for Scholarship Chemistry when they have attempted a range of each style of question.

Type	Data	Method	Goal	Level of Problem Difficulty
1	Complete	Familiar	Clear	Level 3 NCEA
2	Incomplete	Familiar	Clear	Level 3 NCEA
3	Complete	Unfamiliar	Clear	Scholarship
4	Incomplete	Unfamiliar	Clear	Scholarship
5	Complete	Familiar	Unclear	Scholarship
6	Incomplete	Familiar	Unclear	Scholarship
7	Complete	Unfamiliar	Unclear	Outstanding Scholarship
8	Incomplete	Unfamiliar	Unclear	Outstanding Scholarship

Diagram 2 – Varieties of Problems

Scholarship questions are designed to test students' abilities to solve chemistry problems in abstract situations. The questions are set to a high difficulty threshold to avoid any chance that the students may find the questions easy, not test the upper limits of their chemistry knowledge, or not assess at the higher end of the curriculum.

In the diagram on the right, different scenarios for how a student may respond to examination questions are described. The chance of boredom being realised in a Scholarship examination is very small, due the difficult nature of the examination questions. The goal is to get students to progress from the Anxiety region into the Flow region. The determining factor for the degree of success for a student will be their "Skill" in chemistry. This applies to both their content knowledge and ability to solve complex problems.

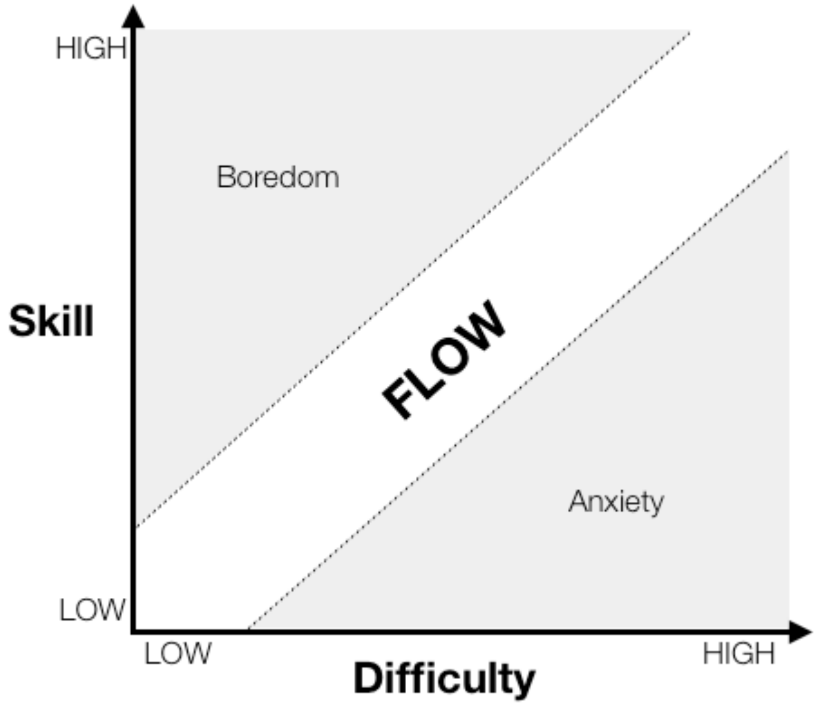


Diagram 3 – Skill v Difficulty (Adapted from Csikszentmihalyi, 1990)

A high skill area will correlate with confidence going into the examination, a good flow of ideas, and an ability to answer most of the questions to the level needed to succeed. A low skill area will conversely result in an inability to answer questions and anxiety about the assessment.

4. Scholarship Examination Technique

Recall v Recognition v Free and Creative Reasoning

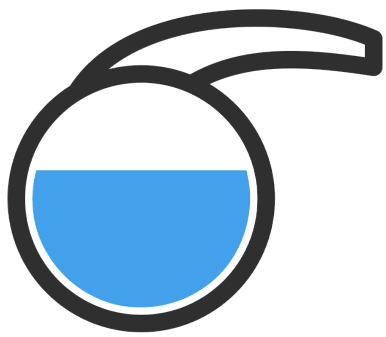
Students who engage successfully in Scholarship questions are those who can adapt and cope with whatever topics are assessed in the examination. Year 13 students generally prepare for Level 3 NCEA examinations by attempting a range of past examination questions, and expecting similar style questions in the final examination that they can respond to with "model answers". This is an approach based on **recall**, and students who engage in chemistry at this level of understanding will not succeed in Scholarship. Some students can expand their understanding further by being able to recognise common familiar concepts, patterns, trends, and scientific ideas within questions, and answer them to a deeper level. This **recognition** level is more adaptive and more likely to bear fruit in Level 3 and Scholarship questions.

Students, however, who can carry out **free and creative reasoning** are able to understand and explore more unfamiliar concepts and answer them using their repository of knowledge. These students are able to achieve Scholarship and Outstanding results through answering a greater number of questions to a more accurate depth of understanding. They generally can also communicate their ideas more accurately and succinctly, saving time and demonstrating to markers their awareness of the core chemistry. The best way to develop these skills is to practise, practise and practise more! Attempt lots of Scholarship problems and learn concepts deeply.

Knowing WHY

Students who aspire to gain a Scholarship award need to focus on knowing the "why" of chemical phenomena. It is not suitable for students to have a simplified "it just happens" approach, because many Scholarship questions demand that they *show* understanding. It is also important that students understand the concepts accurately.

For example, most Level 2/3 students rote learn Markovnikov's Rule, that when it comes to an addition reaction the "rich-gets-richer". However, it is more accurate to dictate that in an addition reaction the carbon of the C=C with the greatest number of hydrogen atoms will be more likely to gain an extra hydrogen atom, and therefore, will determine the major/minor products for the reaction.

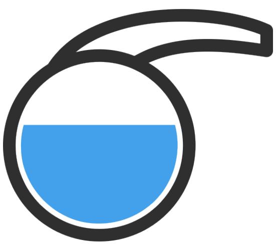


Communicating in Science

Terminology must be used correctly for an answer to be scientifically accurate. Often students do not understand how to correctly explain scientific phenomena using appropriate descriptive words. To earn a Scholarship grade, students must demonstrate a deep understanding of the answer. Only the use of correct scientific terms and ideas will ensure they earn this grade.

For example, there is a significant difference between the following two statements:

- Ethanol is soluble in water because it has a polar -OH group that means it is able to dissolve in a polar solvent such as water.
- *Ethanol is miscible in water because the ethanol molecules contain -OH functional groups, which enables them to form hydrogen bonds with water molecules. These attractions can compete with the existing hydrogen bonds between water molecules, and between ethanol molecules – i.e. the solute-solvent attractive forces are comparable to the solvent-solvent and solute-solute attractive forces. The carbon chain is small enough to not affect the miscibility.*



Another example:

- Sodium atoms lose one electron when they react with another element. The resulting sodium ions have a full outer shell so are more stable.
- *Sodium atoms lose their one valence electron on reaction with a non-metal. The energy required for the removal of the electron is known as the ionization energy. The sodium ions formed do not lose further electrons because they have a full outer shell.*

A final example:

- Ammonium chloride readily dissolves in water, increasing entropy and making the reaction spontaneous despite having a positive ΔH value.
- *A process is thermodynamically favoured (spontaneous) if ΔS(total) is positive. ΔS(total) = ΔS(system) + ΔS(surroundings) The positive ΔH value indicates the reaction is endothermic, resulting in a decrease in surroundings entropy (negative ΔS(surroundings)), which is not favourable. The dissolution, however, does occur, so the increase in system entropy (positive ΔS(system)) must be great enough to offset the decrease in surroundings entropy. This is observed by an increase in random motion of the solute particles as they leave the solid lattice to form dissolved ions in the product solution, where they are in a more dispersed state.*

Students who *do perform well* in Scholarship Chemistry tend to do the following:

- remember uncommon concepts from Level 2 and Level 3 chemistry accurately,
- read questions completely and correctly,
- write answers which are coherent and demonstrate planning prior to their construction,
- write answers supported by correctly balanced equations,
- write answers which link accurate chemistry to the context and requirements of the question,
- correctly use chemical vocabulary and terminology,
- present well constructed calculations with appropriate formulae, working, layout, units and rounding,
- show knowledge of practical laboratory techniques,
- apply knowledge to unfamiliar contexts,
- interpret unfamiliar data or information and process it into usable forms to solve problems,
- show accurate understanding of chemical phenomena - particularly atomic structure and intermolecular forces,
- understand the cause and effect of chemical or physical observations and related changes on a particle level,
- scaffold an answer to address the question in a logical concise manner,
- use time management skills to complete the majority of questions while not writing more than required,
- interpret and draw organic compounds correctly using skeletal structures and draw accurate bonds between atoms,
- take care in writing answers in small text, avoiding any possible confusion for the marker,
- recognise similarities in questions to those studied in past examinations,
- perceptively distinguish useful information from useless information,
- convince the marker that they have a correct understanding of the concepts being explained, usually achieved through consistently using correct chemical principles in explanations.
- extrapolate familiar trends or ideas into more advanced areas of chemistry,
- reflect on the appropriateness and correctness of answers,
- get a good night's sleep the night before and drink lots of water before the exam.

Refer to the NZQA Examiner Reports for further feedback on particular exams.

Students who *do not perform* in Scholarship Chemistry tend to do many of the following:

- go into the examination unprepared and unable to answer the questions in front of them,
- mismanage their time, spend too long on questions and do not complete the examination,
- write inaccurate answers through a lack of understanding of chemical concepts,
- use incorrect terminology or use correct terminology in the wrong manner,
- incorrectly process titration data – such as using non concordant data values,
- do not adequately apply simple equilibrium principles,
- make simple mathematical errors in quantitative calculations - rounding, miss zeros, multiply v divide, factors, etc,
- not read a question completely and only answer part of it, leaving the question incomplete,
- misinterpret data in graphical form, or are unable to account for data in the presented format or use it in answers,
- describe intermolecular forces incorrectly - such as hydrogen bonding within molecules, or refer to "van der Waals" forces rather than the specific forces involved, or worse, use descriptive phrases such as "like dissolves like",
- discuss the bonding and thermochemical changes between particles of different substances incorrectly,
- draw messy organic molecule structures, or not draw bonds between the correct atoms,
- write messy answers which markers cannot understand or interpret,
- do not use the answers to quantitative calculations correctly, or do not understand the significance of the values,
- incorrectly use E and ΔH values when justifying spontaneity or discussing direction of chemical reactions,
- write an incorrect answer and not notice how incorrect or unrealistic it may be,
- do not use equations to justify answers,
- use terms or phrases without explaining them, such as "Le Chatelier's principle"
- sit the examination without proper rest and hydration!

Any vague terms, phrases and "rules of thumb" used in an explanation must be explained. It is not appropriate to simply use statements such as "because of Markovnikov's rule" or core phrases such as "effective nuclear charge" without explaining the core scientific principle, particularly when applied inappropriately. For example when discussing an observation resulting from differences in relative electronegativities of elements, it is appropriate to explain *why* there are differences between the different elements. If in doubt, avoiding these kinds of phrases altogether is wise.

Conceptual Understanding

Any topic in chemistry can be understood on three different conceptual levels. These are the **macroscopic** level, the **sub-microscopic** level, and the **symbolic/representation** level. Students who can explain ideas accurately at *all* three levels will be better prepared to understand and succeed in Scholarship Chemistry.

The macroscopic level: What we can see and touch. *For example: observations, colours, equipment, volumes, physical properties, quantitative measurements, chemical properties, etc.*

The sub-microscopic level: What we understand to occur on a particle level. *For example: particles, attractive forces, interactions, ions, diffusion, electron transfer, structures, etc.*

The symbolic/representation level: How we explain and communicate chemical phenomena. *For example: formulae, calculations, equations, graphs, diagrams, reaction mechanisms, etc.*

When educating students in class, or doing extension tasks, experiments and demonstrations that are followed up with explanations showing links between all three of these key levels will greatly improve and reinforce the deep understanding that students need to have.

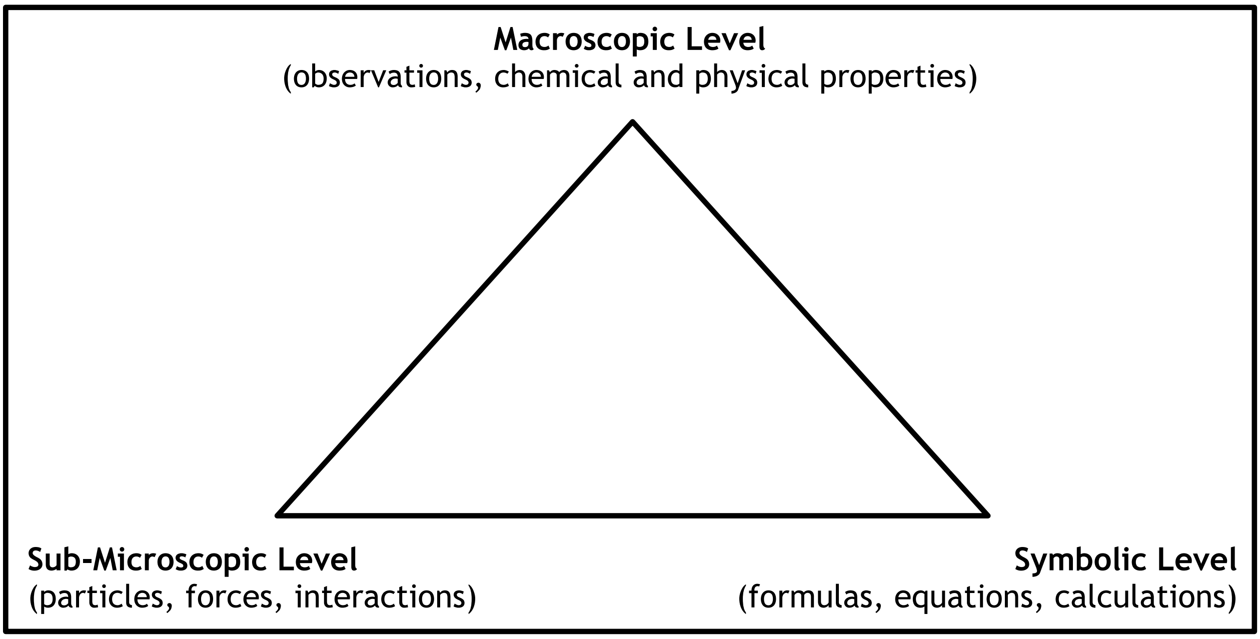


Diagram 4 - Key levels of chemistry conceptualisation (Johnstone, 1991)

5. Assessable Content

The Scholarship Chemistry examination assesses chemistry knowledge up to Level 8 of the New Zealand Curriculum. There is "baseline" knowledge that students should have by the end of Year 13 – which includes the following:

Year 12		
Organic Chemistry • Structural Isomers • Structural Formulae • IUPAC Naming • Geometric Isomers • Oxidation Reactions • Substitution Reactions • Addition Reactions • Elimination Reactions • Markovnikov's and Saytseff's Rules • Alkanes and Alkenes • Combustion Reactions • Addition Polymers • Alcohols • Haloalkanes • Amines • Carboxylic Acids • Physical Properties • Identifying Compounds • Reaction Schemes	**Structure, Bonding and Energy** • Electron Arrangements • Structures of Solids • Allotropes • Electronegativity • Bond Polarity • Molecular Shape • VSEPR • Molecular Polarity • Solubility of Solids • Conductivity of Solids • Melting Points • Solvents • Permanent Dipoles • Bond Energies • Heat of Reaction • Thermochemical Reactions and Equations • Energy Level Diagrams • Activation Energy	**Quantitative Chemistry** • Relative Atomic and Molecular Mass • Molar Mass • Moles • Stoichiometry • Mole Ratios • Percent Composition • Empirical and Molecular Formulae • Concentration • Standard Solutions • Dilutions • Acid+Base Titrations • Indicators • Concordant Results • Water of Crystallisation • Thermal Decomposition
Chemical Reactivity • Particle Collision Theory • Chemical Kinetics • Factors Affecting Rates of Reaction • Chemical Catalysts and Reaction Pathways • pH Calculations + K_w • Equilibrium Constant • Equilibrium Expression • Le Chatelier's Principle • Industrial Equilibriums • pH of Salt Solutions • Weak v Strong Acids/Bases	**Redox Chemistry** • Electron Transfer Processes • Oxidation and Reduction • Redox Terminology • Half Equations and Full Equations • Oxidation Numbers • Redox Species • Oxidising Agents • Reducing Agents	**Qualitative Chemistry** • Precipitation Reactions • Solubility Rules • Ionic Formulae • Ionic Equations • Complex Ions • Ligands • Colours of Ions and Solids • State Symbols • Problem Solving Processes

Year 13		
Organic Chemistry • Hydrogen Bonding and Solubility • Optical Isomers • Reduction Reactions • Nucleophilic Substitution • Condensation Polymers • Acyl Chlorides • Aldehydes and Ketones • Esters and Soaps • Amides and Proteins • Distillation and Reflux • Mild and Strong Oxidising Agents • Acidic and Basic Hydrolysis	**Aqueous Solutions** • Solubility Constants • Solubility Products • Ionic Products • Solubility Expressions • pH Indicators • pH and Precipitation • Complex Ions • K_a, K_b, pK_a, pK_b, pH, pOH, $[H_3O^+]$, $[OH^-]$ • Proton Transfer • Solution Composition • Solution Conductivity • Common Ion Effect • Titration Curves • Drawing Titration Curves • Equivalence Point pH • Buffers	**Electrochemistry** • Oxidative States • Alkaline Redox Reactions • Reduction Potentials • Electrochemical Cells • Electrolysis Reactions • Calculating Cell Potentials • Spontaneity • Standard Half Cell • Cell Diagrams • Salt Bridges • Batteries • Electron Movement
Particles • Ionisation Energy Trends • Attractive Forces • Atomic and Ionic Radii • *s*, *p*, *d* Configurations • Nuclear Charge • Electron Shielding • Temporary Induced Dipoles • Causes of Electronegativity • Lewis Diagrams up to 6 Electron Pairs. • Ionic Lewis Diagrams • Hydrogen Bonding	**Thermochemistry** • Endothermic and Exothermic Processes • Entropy and System Disorder • Dissolving Thermodynamics • Enthalpy of Formation • Enthalpy of Vaporisation, Fusion, Sublimation • Enthalpy of Combustion • Hess's Law • Enthalpy from Heats of Formation	**Quantitative Analysis** • Acid+Base Reactions • Redox Reactions • Iodometry • Back Titrations • Sources of Error • Concordancy • Standardisation • Preparation of Samples

Students will be expected to know Level 2 and Level 3 content ***well*** if they are to cope with abstract Scholarship problems. Advancing their learning by exploring extension concepts and assigning reading from an A-Level textbook is suggested, as the questions they will face are designed to be more complex than standard Level 3 NCEA examination questions.

6. Extension Content

The priority for students should always be to have a comprehensive grasp of chemistry up to NCEA Level 3. Sometimes, however, material arises in the examination which is an extension of what students have been exposed to in their normal schooling and classroom resources. There are many past examination questions that are examples of this, which challenge students to think outside of the box. With a bit of pre-reading on your behalf, you will find yourself better prepared to approach and discuss these more challenging chemistry concepts with students when you get to them as part of your review of past examination work.

While it is not essential that yourself, or students understand this material to a high level, being able to confidently discuss the concepts with the students will help reassure them that the material is accessible and success in the examination is within their grasp.

Further information on each of these different concepts can be found in A-Level UK textbooks, or on the ChemGuide.co.uk website. Some are also explored on the BestChoice website.

Organic Chemistry • Secondary and Tertiary Amines • Dimerisation • Cyclic Compounds • Non-polar Solvents • Protecting Functional Groups • Zwitterions	**Particles, Structure and Bonding** • Hydrogen Bonding • Electrostatic Attraction Strengths • Metallic Bonding Strengths • Born-Haber Cycle • Electron Affinity • Lattice Enthalpy • Second Ionisation Energies • Dipole-Induced Dipoles • Progressive Ionisation Energies • Bonding/Lone Pair Electron Repulsion and Bond Angles • Coordinate Bonding • Axial and Equatorial Bonds	**Quantitative Chemistry** • Back Titration Process • Limiting Reagents • Sources of Error • Reliability of Results/Data • Validity of Conclusion • Concept of Equimolar Species
Electrochemistry • Latimer Diagrams • Concentrations in Electrolysis • Ion movement in Electrolysis • Comparing Relative Reduction Potentials	**Chemical Substances** • Stability of Hydroxides • Appropriate Primary Standards • Multi-Ion Compounds • Dichromate-Chromate Equilibrium	**Thermochemistry** • Entropy and Disorder • Hydration Enthalpy • Spontaneity of Chemical Processes

Practical Chemistry	Aqueous Chemistry	Redox
• Oxalic Acid Thermodynamics • Purification Processes • Drying Agents • Separation Techniques • Steps and Errors • Reflux and Distillation	• Diprotic and Triprotic Acids • Conductivity Curves • pOH Calculations • Cation Acidity • Henderson-Hasselbalch Equation • Indicator Transitions	• Transition Metal Oxidation States • Oxidation State Averages • Transition Metal Colours • pH effects on Redox Reactions • Disproportionation and Comproportionation Reactions

7. Scholarship Marking

NZQA highlights in the assessment specification that there will be no more than four questions in the Scholarship Chemistry examination. Each question is worth a maximum of 8 marks and the grade awarded is determined by the quantity **and** quality of the chemistry understanding communicated in each answer.

The exact grade boundaries for Scholarship and Outstanding Scholarship grades do change year-to-year, but a good guide to work with is:

- To achieve a Scholarship students must achieve a minimum of **half plus one** of the possible grades in the paper (ie 17/32). At least one question must have a grade of **5** or higher.
- To achieve an Outstanding Scholarship students must achieve a minimum of **two thirds plus one** of the possible grades in the paper (ie 25/32). At least one question must have a grade of **7** or higher.

Students do not need to answer every question comprehensively to achieve Scholarship. They simply must do as well as they can in the time given. Attempting *all* questions could potentially contribute *more* to the overall grade than spending time writing long answers on extra paper for only some questions. For example two grades of 3 + 5 are worth more than two grades of 0 + 7. Students need to show enough overall understanding to exceed the grade boundaries for either Scholarship or Outstanding, but not necessarily produce perfect answers. <u>They do not need to get 8/8 for all questions!</u> Remember this when preparing them throughout the year.

The following table is one I have written for my students to help explain the different grade levels that could be awarded to an answer they produce. It is important they have an idea of what may be needed to take a "5" answer to being a "7" answer, and how it differs to NCEA A/M/E grading.

Student's Comprehension of Question and Communication in Answer	Level of Chemistry Understanding Demonstrated	Grade Awarded
Unable to understand the question, or not able to answer the question correctly.	None	0
Does not understand or read the question correctly, but communicates some ideas towards the right answer.	Limited	1
Understands the question, communicates several ideas towards the right answer but does not answer the question fully.	Mediocre	2
Understands the question, communicates chemistry ideas to address most of the question, but does not fully answer the question or uses incorrect terminology.	Simple	3
Understands the question, communicates chemistry ideas that address the question well, but does not use appropriate terminology or complete ideas.	Good	4
Good understanding of the question, answered most of the question accurately, but has not completely explained or linked ideas together or addressed key concepts.	Scholarship	5
Very good understanding of the question, answered it completely using accurate chemistry ideas but not linked key concepts together for a completely extended answer.	Advanced	6
Deep understanding of the chemistry of the question, communicated ideas clearly and accurately to answer most of the question, including linking together the concepts in a coherent manner which explains key/extension concepts well.	Comprehensive	7
Deep understanding of the chemistry of the question, communicated ideas clearly and accurately to fully answer the entire question and demonstrated a complete understanding of the chemistry concepts being assessed.	Outstanding	8

At the conclusion of marking each year, NZQA publishes an *Assessment Report* online for each standard – Scholarship Chemistry is no different. This report details various aspects that were identified by the marking panel as contributing to, or limiting the attainment of, Scholarship or Outstanding Scholarship results by students.

For example, these snippets taken from the 2021 Assessment Report:

> **Part A: Commentary**
>
> Candidates should ensure that they have prepared for this examination by studying and developing an understanding of the various different aspects of the Chemistry curriculum, regardless of which internal or external assessments they have entered for in NCEA. The questions in the examination are drawn from quantitative analysis, organic chemistry, spectroscopy, redox and electrochemistry, rates of reaction, chemical equilibria, aqueous systems, particles, substances, and thermochemical principles. Candidates who were successful in this examination were able to interpret and answer a majority of the questions, regardless of which area of the curriculum they were derived from. Candidates who did not reach a grade high enough for the awarding of Scholarship often had left large parts of the examination unanswered.
>
> Each part of a question contributes evidence towards the awarding of Scholarship, and unanswered questions

> **Part B: Report on Performance**
>
> Candidates who were awarded Scholarship with **Outstanding Performance** commonly:
>
> - could correctly complete calculations to determine Q_s values
> - could compare and contrast the $K_s(Ca(OH)_2)$ with Q_s values to justify the presence or absence of a precipitate
> - used equilibrium equations and principles to justify the loss of a hydroxide precipitate on addition of dilute acid
> - justified redox changes of varying complexity with use of balanced equations and cell potential calculations

> Candidates who were awarded **Scholarship** commonly:
>
> - could determine the concentration of species from mass and volume values, and use these to determine Q_s values
> - calculated the pH of a buffer solution
> - used standard reduction potentials to calculate cell potential values and write balanced equations for the relevant redox reaction
> - could determine constitutional isomers from a molecular formula

> Candidates who were **no**t awarded Scholarship commonly:
>
> - did not show correct understanding of chemical equilibria
> - did not understand the formation of calcium hydroxide from the reaction of calcium with water, despite the K_s value provided
> - could not determine oxidation states for elements
> - could not calculate Q_s values from concentrations
> - assumed that the pH of a calcium hydroxide solution would be 7, and then incorrectly used this as the basis for the hydroxide ion concentration in Q_s calculations

These reports are very detailed, and you should take the time to read through these each year, alongside the paper and schedule, to help further your understanding of the examination questions and answers, which will then further improve the guidance you can provide to your students.

8. Preparing Students in Year 12 for Scholarship

Due to the abstract nature of many Scholarship examination questions, it is recommended to prepare students for this kind of approach to thinking and problem solving in Year 12. The Chemistry Olympiad is a great pathway available for Year 12 students that provides suitable opportunity for them to develop these skills.

While the primary goal of many students preparing for the Chemistry Olympiad is to study high level chemistry and represent New Zealand at the International Chemistry Olympiad, not all students will progress that far but will still benefit from completing at least the first two steps of the process. The stages to the New Zealand Chemistry Olympiad team selection are as follows:

All Term 3: Students study Year 12/extension content and past exams.

Late Term 3: Students sit the Olympiad Selection Examination.

Summer Holidays: Top 80–90 students selected to study Level 3 and extension content.

Mid-Term 1: Prepared students from the original selected 80–90 sit the Training Camp Selection Examination

Autumn Holidays: Training camp for top 25-30 selected students, top five students selected to represent NZ.

Term 2: Top five students study University level content in preparation for international competition (four in team and one reserve).

Winter Holidays: Top four travel and represent NZ at competition.

Preparing for the selection examination and sitting it will provide a Year 12 "version" of the problem solving observed in the Scholarship examination. Some students may succeed well in the first selection examination and elect to continue through the remainder of the Olympiad training programme—this will certainly not disadvantage them for Scholarship, and should be supported.

Designing an Olympiad Training Programme

Teachers should ensure that students are first operating at Merit/Excellence level in their Level 2 content first. It is wise to not start preparing students for the Olympiad until the start of Term 3, once sufficient content has been covered in class.

Throughout Term 3 and early Term 4 students should continue to study their standard topics in class, but complete an additional Olympiad training programme outside of class. This is normally best organised as a weekly meeting to address practice Olympiad problems, discuss extension concepts, followed by assigned homework tasks which their teacher can design to extend their understanding (see image below).

An Olympiad training programme should be focused on introducing students to abstract problem solving, reinforcing to them that *understanding* chemistry is key to success, and providing them with extension content.

Chemistry Olympiad

Term 3 Prep

Worksheet # 1

Ethanol – CH_3CH_2OH

1) Show the organic or inorganic reactants and conditions needed to convert ethanol into each of the following organic compounds:

polythene
chloroethane
1,2-dibromoethane
ethanoic acid
ethan-1,2-diol
ethene
ethyl ethanoate
ethane
ethanal
aminoethane
magnesium ethanoate
ethyl ammonium chloride

2) When isolated, describe a chemical or physical test you could use for each organic product.

3) What is the minimum number of inorganic chemicals that are needed to enable all the above reactions to occur?

Each week students should explore a particular topic area of Year 12 chemistry, with matching practice Olympiad questions to work from. The best place to get these styles of questions is from the past Olympiad selection examinations. These can be found online along with further information on the Olympiad programme here: http://www.chem.canterbury.ac.nz/Olympiad/

The end goal for most Year 12 students at the conclusion of this Term 3 training programme is that they will then study throughout the spring holidays, ready to sit the Olympiad Selection Exam in late October (early Term 4). The Year 12 Olympiad section on BestChoice.net.nz will be useful for students as well at this point in the year. Teachers will need to register students for the final examination online, details of which can be found on the Olympiad website above.

The results for this examination can be used as a good indicator for the potential each student has for success in Scholarship Chemistry the following year. Gold or Silver awards are a good indication of readiness. Bronze or Participation awards are not as good, and can be used to kick-start students into studying more over the summer holidays. Students who are unwilling to dedicate time towards becoming competent, knowledgeable students in Year 12 chemistry are unlikely to dedicate time to a similar Scholarship programme in Year 13 and should consider focusing their studies elsewhere.

9. Designing a Year 13 Course

The Scholarship examination is aligned with Level 7 and Level 8 of the New Zealand Curriculum (NZC). While assessment is only one aspect of course design, any full-year Year 13 course should ideally offer students between 18–24 credits. As there are a total of 28 credits available in NCEA Level 3 chemistry, it is not possible to assess every topic and assessment should not be used to determine the course design for Scholarship students. Some aspects of a Scholarship focused course may need to be taught as extension outside of class to develop a broad base of knowledge.

External Achievement Standards	Internal Achievement Standards
3.4 Particles and Thermochemistry	3.1 Practical Investigation
3.5 Organic Chemistry	3.2 Spectroscopic Analysis
3.6 Aqueous Chemistry	3.3 Chemistry Processes
	3.7 Electrochemistry

External Examinations

Students need to be familiar with particles, thermochemical principles, organic molecules, and aqueous systems. These areas of the NZC are assessed in three external examinations and students who do not have a grasp of these topics will not be prepared for Scholarship Chemistry. Students do not need to sit all three examinations, but the topics should be included in a programme of learning for those students endeavouring to achieve Scholarship. This could be achieved in some areas through providing resources, assignments, and support workshops outside of class if needed.

Electrochemistry

Students need to be familiar with electrochemical cells and the use of standard reduction potentials in the determination of the spontaneity of chemical processes. The internal assessment associated with this area of the NZC adequately encapsulates electrolytic and electrochemical cells and could be considered for inclusion in a course.

Spectroscopic Analysis

It is essential that students have an ability to interpret and understand the data found in IR, ^{13}C NMR, and MS spectra, as these can all be used in a variety of ways in scholarship exam questions. Students extend their organic chemistry understanding by exploring spectroscopic analysis and have the potential to achieve better outcomes than others who have not. The internal assessment can be completed within two to three weeks if utilised as one of the standards included in the course at the end of the organics topic.

Practical Investigation

A common consideration when preparing a course for Scholarship students is whether to include this internal achievement standard or not. Regardless of whether this standard is assessed or not, the underlying quantitative principles are an important aspect of the NZC, are essential to Scholarship Chemistry, and must be included in some capacity in a programme of learning.

The skill set of gathering and processing data can be replicated by carrying out set titration tasks and collecting and processing the titre values, without the need for the full write up of a report. Practising the calculations and carrying out practical techniques are important, but teachers should not feel they must provide this only through the 3.1 internal assessment. This can be covered through extension work outside of class if time is limited and the internal assessment can not fit into a year plan.

Additionally, it is wise to engage students in awareness of the range of volumetric analysis methods out there such as redox titrations, precipitation titrations, complex ion titrations, back titrations, and competition titrations. While all of these methods use different calculation procedures, chemical equations, and problem solving skills to solve, they all support students in developing quantitative skills. While something as straight forward as “iodate and vitamin C”, as commonly used in a 3.1 internal task, could feature in a Scholarship examination, the question is going to be far more complex than anything faced in a 3.1 investigation.

Chemical Processes

Extension, wider thinking skills, and an ability to communicate are important skills in the Scholarship examination. While this standard is not essential for building a core base of chemistry knowledge, it has great potential to reach into an area of the NZC which is not assessed anywhere else. It could be offered as an optional standard for some students to complete outside of class for extension purposes, or serve as an option for increasing the possibility of subject endorsements for Level 3 Chemistry.

In conclusion

Ultimately, students should enjoy what they are learning no matter what is taught and what is assessed, building excitement about the world through the lens of chemistry. Past Scholarship examination papers provide a great insight into the ways in which different topics could be assessed at a Scholarship level. I recommend you spend some time reading through these exams, trying the questions yourself, reviewing the schedules and examiners reports, then take time to reflect on the programme of learning available to your students to determine whether any changes could be made, or how a balance could be struck between what is taught “in class” to all students, versus what could be taught outside of class as extension.

10. Constructing a Scholarship Programme for Year 13 Students

The best approach to a Scholarship programme for Year 13 students is one that involves extension and problem solving throughout most of their Year 13. It should ideally start towards the end of Term 1 and finish early in Term 4. It is not the sort of thing which can be tacked onto the end of level 3 revision in Term 4 - there is far too much to be done!

Students must be readily enthused and engaged in a training programme throughout the year, or else not bother embarking on the journey at all. It is wise to first outline the demands to students, give them some example questions, then request that they join up to the extra programme - ensuring they actively "buy into" Scholarship. They will need to consistently aspire towards achieving Excellence level results in their formative and summative assessments, as well as have a keen interest in pursuing understanding further than that level. This takes time and good study habits to ensure the outcomes are met consistently throughout the year.

A training programme can be achieved either in class time, or outside of class time at regular intervals set aside by the teacher. Most students will benefit from just focusing on standard Level 3 content in class, developing a strong understanding of that level of content there, while exploring additional tasks outside the classroom to extend and bring into focus new ideas. Additional sessions with students outside class is ideal for teachers as well, as the exploration of Scholarship content and problems in class time does tend to impact on the ability for the class to cover the standard content during the short school year. This does require a time commitment from teachers, but the benefits from such a commitment are rewarding.

Towards the conclusion of the first topic of the year, teachers could start assigning sections from ChemGuide.co.uk to extend the understanding of the studied topic. To see why this website is recommended, visit it and read a section on any relevant topic, and you will quickly see how useful this will be to helping extend students.

Teachers at this point should also provide example past Scholarship questions for the students to work through and solve. Providing answers and explanations after the tasks have been completed ensures students do not "take the easy way out" and simply read the answer when faced with what seems like an impossible question to solve. Learning ***how*** to face and solve these kinds of questions is fundamental to developing the tenacity and skill that is crucial to success in Scholarship

Chemistry. Additional problem-solving tasks beyond this can be found on BestChoice.net.nz and in other printed resources, such as past NZIC examinations.

As further topics are covered in class, further problems and answers can be provided for students to work through outside class.

An approach I recommend involves providing students with relevant questions from any of the past examinations, other than from the three preceding years' exams. I suggest leaving those three examination papers instead for the students to complete as a "whole paper" during the spring school holidays, or during Term 4.

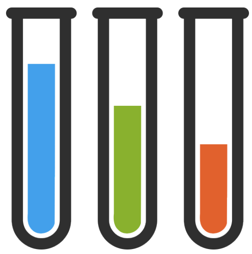
By the end of Term 3 ideally the entire learning programme for Year 13 chemistry should be completed or nearing completion. Students at this stage should have experienced several different styles of Scholarship questions for all the topics covered throughout the year, as well as having finished reviewing all the content in their class resources, or workbooks.

Once they have reached this point in time, that is when it is best to start focusing students away from individual topic-specific questions, and instead move them towards learning how to complete a whole examination in a timed environment. This is where the three preceding years' exams come in.

For each of the three examinations students should:

- Print out the examination as one whole document.
- Complete the examination in a timed environment – closed book with no resources to guide them.
- Use the Marking Schedule to review their examination answers, taking care to recognise the correct use of scientific terminology in the provided model answers.
- Review any content they are unsure about following the exam.
- Compare their answers to the answers in the Top Scholar, Scholarship, or Outstanding papers.
- Read the examiner's report to identify the common mistakes and criteria for different questions which contributed to Scholarship/Outstanding grades, and see if they made similar errors that they can learn from.

By engaging in and completing a full attempt and review of these examinations they can become as aware as they possibly can be of the approach and detail expected in Scholarship examinations.



11. Useful Resources

"For the hundredth time—I have no idea how to make crystal meth."

Websites

www.nobraintoosmall.co.nz
www.bestchoice.net.nz
www.sciencescribe.co.nz
www.chemguide.co.uk
www.rsc.org/resources-tools/education-resources/
www.nzqa.govt.nz
chem.libretexts.org

Textbooks and Workbooks

UK A-Level Textbook: **Advanced Chemistry**; M Clugstone & R Fleming ISBN 0199146330
Level 3 Textbook: **Chemistry for NCEA Level Three**; M Croucher; Nelson Cengage Learning
Study Guide: **ESA Study Guide - Year 13 Chemistry**; S Boniface, J Giffney; ESA Publications

Chemistry Teacher Networks

Ian Torrie's Monthly SCENZ Newsletter – Email Ian to join: ian.torrie@stcuthberts.school.nz
Facebook for NZ Chemistry Teachers - https://www.facebook.com/groups/NZChemistryteachers/
SCENZ – Secondary Chemistry Educators of New Zealand - https://nzic.org.nz/scenz

References

A.H. Johnstone (1991) "Why is Science Difficult to Learn? Things are Seldom What They Seem" *Journal of Computer Assisted Learning* vol.7, 75-83.
M Csikszentmihalyi (2008) *Flow: The Psychology of Optimal Experience*. Harper Perennial Modern Classics
K. S. Taber (2013) "Revisiting the chemistry triplet: drawing upon the nature of chemical knowledge and the psychology of learning to inform chemistry education", *Chemistry Education Research and Practice*, 14, 156-168

Feedback, suggestions and comments for future versions are welcomed.