Chemistry In Action!

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ChemEd-Ireland 2022 - chemistry in action

Contents #121

Contributions on any matter of interest to second-level chemistry teachers are welcome. Normally the results of research (chemical or educational) are **not** published, except in a general form or as a review. Articles should be submitted electronically (email or disc) to **peter.childs@ul.ie** together with a printed copy.
For general information, subscription details etc. see inside back cover.

Cover design: George Fitzgerald, Möbius Design, Limerick
Cover photo: The electrochemistry workshop at ChemEd-Ireland 2022: L to R Ms. Aine Coogan (TCD), Dr. Natalia Garcia Domenech (TCD) and Mr. David O'Connell (CBC Cork) (photo: P.E.Childs)

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Editorial #121

Proceedings ChemEd-Ireland

The Spring issue is the Proceedings issue from the previous year's ChemEd-Ireland conference, which in 2022 was held at TUS Limerick. Some years it has proved difficult to get speakers to turn their talks into written articles, but this time we have a good response. The purpose of the Proceedings is to give a permanent record of the conference, but also to make the talks accessible to a wider range and larger number of teachers. Now that *CinA!* is also produced electronically it also means that the talks are available worldwide. Thanks again to Marie Walsh and her team at TUS Limerick for an excellent job in organising the conference, in a superb venue. By coincidence, the 2023 ISTA annual Conference is also in TUS Limerick, the main day being April 1st.

Sustainability – the new STEM theme

The theme of the 2023 ISTA conference in TUS Limerick is 'Science Education for a Sustainable Future.'
ISTA Annual Conference 2023 – Science Education for a Sustainable Future – Irish Science Teachers' Association
This theme is both topical and timely, in the light of the energy crisis and climate change, with pressure on resources worldwide and a continuing problem with plastics pollution, water and air pollution.

ChemEd-Ireland 2023 in TCD has the theme of Green Chemistry and this is closely related to Sustainability. The 2024 ICCE in Thailand has the theme of 'Power of Chemistry for advancing SDGs'. This refers to the Sustainability Development Goals of UNESCO adopted in 2015 (UNESCO and Sustainable Development Goals).

Green chemistry and sustainability

The mantra of green chemistry and its new incarnation, sustainability, is **reduce, reuse, recycle.** The main idea is to use less energy and fewer chemicals, to produce less waste, and to use less hazardous chemicals and produce less hazardous waste. Green chemistry goes back to the 1990s and the drive for sustainability dates from the early 21st century. STEM subjects, especially chemistry, have a major role to play in educating society in the importance of these ideas. STEM education **for** sustainability means providing the scientific background so that students and the public understand the issues involved and what can and can't be done. Science is necessary to understand nearly all areas and issues in sustainability, and in identifying and solving problems. This is sustainability **through** science education. But science educators have another role to play. They must also demonstrate in their own teaching, especially in relation to practical work, what sustainability means **in** science education. Science teachers must show that they have thought about reducing the use of energy and chemicals and the waste produced in their teaching. They must think about how chemicals and equipment can be **reused**, rather than thrown away. Also teachers must think about how the products from laboratories can be **recycled** in appropriate ways. I also think that we need another R: **redesign**. In order to achieve the aims of reducing, reusing and recycling, we must also rethink and redesign what we do. For example, in titration we can rethink how we do them: to use lower concentrations, smaller volumes, plasticware rather than glassware, microscale rather than large glassware, and alternative and more benign chemicals. We often use 1 M solutions in titrations and large volumes (25 mL portions). The reactions work well at 0.1 M and we could use 10 mL portions, or even droppers. Using plastic apparatus where possible will reduce breakages and the need for replacements. Copper salts can easily be recovered and recycled for subsequent use, with very little waste. Microchemistry in particular, using droppers and plastic sheets, or petri dishes to contain gases, can drastically reduce the amounts of chemicals used and hence the waste produced. Heating smaller quantities uses less energy and smaller, less concentrated solutions also uses less water. **Sustainability in chemistry teaching will be one of the challenges for the future.**

Peter E. Childs
Hon. Editor

Contents of #121

The main contents of this issue are the talks given at ChemEd-Ireland in TUS Limerick in 2022. All the main speakers sent in written versions and together they make a useful and interesting collection of articles.

The first one on 21st Century Skills by Peter Childs asked and tried to answer the question "Can we teach chemistry content and at the same time develop 21st century skills?" (p. 11) Such skills are what employers are looking for and also equip students for further study as well as the workplace.

Geraldine Mooney Simmie, now Director of Epi*Stem at UL, talks about some ideas for teaching about the atom (p. 23).

Billy Madden from TUS Limerick talks about his experiences of online learning during the pandemic. (p. 27)

Naomi Hennah came over from England to talk on laboratory learning, a talk sponsored by the RSC. (p. 32)

Catherine Martin and Ebru Eren from UL talked about teaching in multilingual classrooms, as part of the Erasmus+ project ESTA. Many teachers in Ireland at first and second levels, are now teaching in multilingual classrooms, so this is very relevant. (p. 36)

Johanne Brolly, who is the RSCs Education Officer in N Ireland (equivalent to John O'Donoghue) gave an excellent talk on 'Teaching about moles', which should be very helpful to all those who have tried to teach the topic effectively. A nice blend of theory and practice. (p. 43)

Finally, Fiona Desmond, Chief Examiner for LC Chemistry, gave some of her thoughts on the examination, in the light of 2-3 years of disruption. (p. 50)

There are also brief reports on two workshops: one on 'Sparking students' interest in electrochemistry' from David O'Connell (p. 55) and one on 'Bioplastics' from the Junior Cycle Team Science (p. 58.)

The Education News and Views section mentions (with links) some new reports relating to STEM education.

Education News and Views

Special issue

For the last few years CinA! has switched to publishing two larger issues each year, Spring and Autumn, instead of three, due to increases in postage and printing costs. CinA! is also now mainly distributed electronically, with a limited number of hard copies printed. This year we will be publishing a special Summer issue with articles on the Erasmus+ project DISSI, of which UL is a partner. DISSI is about 'Diversity in Science towards Social Inclusion – Non-formal Education in Science for Students' Diversity.' This will be distributed in the usual way in Ireland but copies will also be sent to the DISSI partners.

Home - DiSSI

Previously we have produced special issues on the SALiS and TEMI projects.

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JC Results late again

In 2022, the Junior Cycle Profile of Achievement (JCPA) fully replaced the Junior Certificate.

Junior Cycle Profile of Achievement grades

Percentage Range	Grade
90 or over	Distinction
75 but less than 90	Higher Merit
55 but less than 75	Merit
40 but less than 55	Achieved
20 but less than 40	Partially Achieved
Less than 20	Not Graded

The results for 67,130 students were finally released on 23rd November 2022. This sets a new record for lateness in releasing the results, nearly 3 months after the students started either TYO or the senior cycle. English, Irish and Maths have ordinary and higher levels, but all other subjects, including Science, have a common paper with no choice.

The main reason for the delay in marking and issuing results was ascribed to a shortage of examiners, who are usually teachers. According to the SEC, there were 1,270 written examiners for the Junior Cert this year, compared to 1,756 in 2019.

The jury is still out as to whether this new Science course and exam is a good preparation for the LC science subjects, which apart from Ag. Science have still not been revised. The gap between JC Science and the LC Sciences has increased and must create problems for both students and teachers. The last year when all students were graded only on exams was 2019, due to the covid interregnum. In the table below the 2022 results are compared with 2019.

Subject	Level	Year	Total Candidates	Distinction	H Merit	Merit	Achieved	Partially Achieved	Not Graded
English	A	2019	51,226	2.0	18.8	50.7	22.6	5.4	0.3
English	A	2022	54,083	2.1	18.1	51.0	23.3	5.1	0.3
English	G	2019	12,353	2.3	25.2	47.6	17.9	6.0	0.9
English	G	2022	12,166	2.1	22.0	47.5	20.8	6.9	0.7
Business Studies	C	2019	36,267	1.9	27.4	48.4	15.5	6.3	0.6
Business Studies	C	2022	37,341	3.3	22.0	43.2	21.6	8.7	1.1
Science	C	2019	59,543	2.0	25.4	49.0	17.2	5.9	0.5
Science	C	2022	62,554	3.7	25.5	41.7	19.3	8.9	0.9
Irish	A	2022	29,540	2.6	20.6	42.2	23.9	9.3	1.4
Irish	G	2022	24,732	2.3	17.9	44.7	24.2	9.5	1.3
Gaeilge T1	A	2022	2,599	3.6	23	47.9	20.9	4	0.5
Gaeilge T1	G	2022	136	2.9	15.4	47.1	23.5	8.8	2.2
Mathematics	A	2022	40,275	3.6	22.6	44.5	21.3	7.4	0.6
Mathematics	G	2022	25,699	3.3	31.1	42.3	16.3	6.7	0.5
History	C	2022	56,859	2.8	22.6	45.1	21.4	7.3	0.7
Geography	C	2022	58,608	2.5	23.5	46.3	20.4	6.9	0.4

STATE EXAMINATIONS COMMISSION

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Future ChemEd-Ireland venues

Since the 26th conference the venue has alternated between the West and East coasts.

2024 43rd UCC
2025 44th TU Dublin
2026 45th UL
2027 46th DCU
2028 47th TUS-Limerick

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ChemEd-Ireland 2023

'Green Chemistry in the Classroom'

This year's ChemEd-Ireland conference will be held in Trinity College, Dublin on the 21st October, hosted by the Chemistry Department and organised by Dr John O'Donoghue and his team.

"Everyone is welcome to join us in Trinity College Dublin on the 21st of October 2023 for the 42nd ChemEd-Ireland conference. We already have a few local speakers arranged and we are currently in the process of confirming some international ones. There will also be stands and posters from teachers and numerous organisations, including the new professional development service for teachers: Oide. We will also be hosting a social evening with some light talks on Friday the 20th of October for everyone who has travelled up and decided to stay the night before."

John.ODonoghue@tcd.ie

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STEM Consultation Report, March 2023

89b3d3e7-e547-4a4b-8281-a166b6023c77.pdf (www.gov.ie)

In March 2023 the Minister of Education Norma Foley launched the STEM Education Policy Group Consultation Report, as part of the STEM Education Policy Statement 2017-2026.

gov.ie - Minister Foley and Minister O'Gorman launch STEM Education Implementation Plan to 2026 (www.gov.ie)

(ee gov.ie - STEM Education Policy (www.gov.ie))

Introduction

As part of the ongoing implementation of the STEM Education Policy Statement the Department of Education (DoE) is currently developing a new STEM Education Implementation Plan which will be informed by learnings the STEM Education Implementation Plan 2017-20191(Phase 1, the Enhancing phase), and the findings from a consultation process including focus groups with relevant stakeholders.

The Department of Education(DoE) held a series of Focus Groups(FGs)with thirteen *stakeholder groups between 17 February and17 May 2022.The DoE worked in conjunction with the Department of Children, Equality, Disability, Integration and Youth (DCEDIY) for the Early Learning and Care (ELC) focus group. The Focus Groups were one element of the DoE's review of implementation, and they were informed by an earlier public consultations process. The purpose of the Focus Groups was to capture the voice of teachers, early years educators, school leaders, learners, parents and education stakeholders on a range of issues that emerged from the initial set of consultations.*

The Focus Group questions were informed by earlier stakeholder feedback provided through the STEM Education Policy Statement public consultation. A series of discussion topics was designed for each of the Focus Groups and provided to participants in advance. These formed the basis for discussion during the Focus Group sessions and covered a range of issues, such as:

- *Successes and challenges in implementing STEM.*
- *STEM Learning and Assessment Practices.*
- *Leadership of STEM education*
- *Teacher and Early years Educator Capacity in STEM education.*
- *Partnerships with external stakeholders.*

The Focus Groups were organised and coordinated by the Curriculum and Assessment Policy Unit (CAP) in the DoE (and in conjunction with DCEDIY for the early learning and care focus group),which identified and contacted the participants in advance of the live focus groupsessions.H2 Learning facilitated the technical design and delivery of the focus group sessions online and subsequently analysed the discussion transcripts and compiled the STEM Education Focus Group Consultation Report.

This report provides a high-level overview of the perspectives that were shared by the participants across the thirteen focus groups. The participants shared a wide range of views, and these were initially categorised as either observations or suggestions. Subsequently, the observations were divided into successes and challenges, as contributors shared a wide range of experiences during the focus group sessions. The observation statements captured examples of current practice or contributors' views on a particular issue they were asked to comment on, while the suggestions proposed a possible action that could be taken to improve a particular topic or issue in the future. The report categorises these contributions under the four pillars of the existing STEM Education Policy Statement.

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The findings from this Consultation fed into the STEM Education Implementation Plan to 2026.
Layout 1 - 3a904fe0-8fcf-4e69-ab31-987babd41ccc.pdf (www.gov.ie)

The Implementation Plan is built around 4 pillars:

Pillar 1. Nurture learner engagement and participation.

Pillar 2. Enhance early years educator and teacher skills.

Pillar 3. Support STEM education practice.

Pillar 4. Use evidence to support STEM education.

The consultation process has shown that there is a need for a continued focus on the implementation of STEM education across the education system with the programme of work to 2026 to include;

•Provision of examples of what STEM education can look like from early learning and care to post-primary level.

•Supports on what integrated STEM looks like at primary and post-primary school level.

•A range of quality professional learning experiences for early years educators and teachers across primary and post-primary schools to support staff with STEM content knowledge, in planning and implementing integrated STEM activities across all three levels.

•Ensuring that student teachers in initial teacher education have opportunities to engage in and teach STEM lessons.

•Enhancing the partnership between schools and business/industry and the research community.

•Provision of information on STEM careers and courses and equitable access to STEM/STEM and the Arts role models.

•Provision of a central repository of resources and exemplars of STEM/STEM and the Arts learning opportunities.

•Continued review of STEM curriculum and assessment across all levels.

•Provision of funding to support projects that engage children and young people in STEM in primary and/or post primary schools.

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Joint Committee on Education, Further and Higher Education, Research, Innovation and Science debate - Tuesday, 28 Feb 2023

https://www.oireachtas.ie/en/debates/debate/joint_committee_on_education_further_and_higher_education_research_innovation_and_science/2023-02-28/2/

The Joint Committee on Education, Further and Higher Education, Research, Innovation and Science had a debate on STEM in Irish Education on Feb. 28th., which you can read at the link above.

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Report on International Reflections on STEM Education

A joint RIA/AALEA report, 2/2/23

Event Report on International Reflections on STEM Education | Royal Irish Academy (ria.ie)

ALLEA (the European Federation of Academies of Sciences and Humanities) and the Royal Irish Academy (Acadamh Ríoga na hÉireann) organised the symposium "International Reflections on STEM Education - Effective teaching and learning to address future challenges" on 25 October 2022 in Dublin.

The symposium, which was organised jointly by ALLEA with the Royal Irish Academy in Dublin, brought together local and European experts in the fields of science, technology, engineering, and mathematics (STEM) education to discuss current challenges and opportunities in the field. Read the event report here.

This report highlights the need for a holistic approach to (STEM) education to provide future generations with the requisite knowledge, skills, attitudes, and values to enable them to address complex real-world problems. Other emerging themes relate to the need for a breadth of thoroughly validated teaching materials, the key roles of Initial Teacher Education and Teachers' Professional Learning, as well as the importance of continuous interactions between educators, researchers, and policymakers to improve STEM teaching and learning.

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Pioneer of microchemistry dies

Professor John Bradley (1937-2022), from the University of Witswatersrand in South Africa, died on Christmas Day, 2022. He was a pioneer of microscale chemistry, using special plastic kits produced by RADMASTE, especially for use in developing countries,. You can read a short obituary by Bob Worley at Professor John Bradley obituary (rsc.org) and the next PoSE article in SCIENCE (May 2023) will look at his contributions to microscale practical work. Although born and educated in the UK, he spent 58 years in South Africa and had a major effect on how chemistry is taught in African schools.

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Proceedings: ChemEd-Ireland 2022

This annual conference for chemistry teachers and chemistry education researchers was held face-to-face for the first time in three years in TUS on Saturday October 15th 2022.
Some eighty teachers and lecturers gathered for a series of talks and workshops on the theme of 'Renewal and Reinvigoration in Post-covid Chemistry Classes.'
The programme is shown below, and articles based on the talks are given in the following pages in the order of the programme below. Thanks to those speakers who submitted written versions of their presentations.

TUS TUS

ChemEd-Ireland 2022

Programme - October 15th, 2022

9:00 - 9:30 a.m.	Registration: tea, coffee and pastries
9:30 - 9:45 a.m.	Welcome
	Dr Vincent Cunnane, President TUS. Dr Daniel Walsh, Head of Dept Applied Science TUS
9:45 - 10:15 a.m.	Dr Peter Childs, Emeritus Senior Lecturer, University of Limerick
	Teaching 21st century science with 21st century skills
10:15 - 10:30 a.m.	Sheila Porter and Eoghan O'Brien, SciFest and Laurel Hill Secondary School, Limerick
	SciFest – a teacher's perspective
10:30 - 11:00 a.m.	Dr Geraldine Mooney Simmie (Director, EPI*STEM) and Tara Ryan (STEM Researcher)
	*CPD approaches bringing Chemistry to Life in the classroom: a HEA Performance Project with EPI*STEM*
	EPI*STEM National Centre for STEM Education at the School of Education, University of Limerick
11:00 - 11:20 a.m.	Coffee and stands
11:20 - 11:40 a.m.	Dr Mary Shire, Regeneron, Limerick
	STEM Teaching activities at Regeneron
11:40 - 11:55 a.m.	Billy Madden, Technological University of the Shannon, Midwest
	Pandemic on-line teaching and learning: What to keep
11:55 - 12:30 p.m.	Naomi Hennah, Northampton School for Boys
	RSC Sponsored Talk: *Laboratory Learning*
12:30 - 13:05 p.m.	***Workshops Round 1**
13:05 - 13:40 p.m.	Lunch: Green Rooms Canteen (Please tell staff if you have special dietary requirements)
13:40 - 14:15 p.m.	***Workshops Round 2**
14:15 - 14:35 p.m.	Robert Masterson, Loreto College, Mullingar
	PDST Resources for Chemistry Teaching
14:50 - 15:05 p.m.	Dr Catherine Martin and Dr Ebru Eren, University of Limerick
	ESTA Project: Teaching in multilingual classrooms
15:05 - 15:35 p.m.	Dr Johanne Brolly, RSC
	Thinking About Moles
15:35 - 16:05 p.m.	Dr Fiona Desmond, Chief Examiner Chemistry, State Examinations Commission
	Challenges in Teaching, Learning and Assessing LC Chemistry – SEC Chief Examiner's Perspective
16:05 - 16:20 p.m.	Dr John O'Donoghue, Trinity College Dublin and RSC
	Closing Remarks and handover

*Please sign up for workshops at registration: You can choose one from before and one after lunch. *Spaces are limited in each workshop. First come-first served.

Workshop 1:	Taking Charge Global Experiment - Royal Society of Chemistry: Dr John O'Donoghue
Workshop 2:	Medicine Makers, Dr Martin McHugh, SSPC
Workshop 3:	Sparking students' interest in electrochemistry: David O'Connell
Workshop 4:	Are Bioplastics a solution to Single Use Plastics – Junior Cycle Team Science

Thanks to Royal Society of Chemistry, SciFest, Ocon Chemicals, PDST, JCT, SSPC, EPI*STEM, Folens, ESTA Project and Everyone contributing to workshops and talks. Thanks to Tracey Farrell, Josephine Treacy and John Hannan and all TUS staff who helped in any way.

TUS
Technological University of the Shannon: Midlands Midwest
Ollscoil Teicneolaíochta na Sionainne: Lár Tíre Iarthar Láir

Chemistry: A Core Subject in Technological University of the Shannon – Midwest

Home - TUS

The Technological University of the Shannon (TUS) – Midwest, formerly known as Limerick Institute of Technology (LIT) - can trace its roots back to the School of Ornamental Art in Limerick, opened on 3 July 1852. For much of the history of the school it was constituted as the Municipal Technical Institute which was opened in 1910. By the 1970s, it had grown to such a degree that a new campus had to be acquired in Moylish, on the north side of Limerick city.

The Limerick City Vocational Education Committee (VEC) founded the college in 1975 as the Limerick Technical College (LTC). The Institute was constituted as the Limerick College of Art, Commerce and Technology (Limerick CoACT) in 1980, became a Regional Technical College in 1993, and finally an Institute of Technology in 1997 as LIT. In 2021 TUS was formed following the merger of the LIT locations with Athlone Institute of Technology.

The importance of Chemistry as a core subject was established with the Moylish campus. The Department of Applied Science that developed at that location started its offering with City and Guilds technical certificates and diplomas. It also established links with local industry that informed the course development to meet the skills needs of that industry, whether heavy chemical, fine chemicals or pharmaceutical. The strengths of the Department lay in chemical instrumentation and analytical methods, although these have diversified as new programmes were developed and became part of the Department offering.

Currently all programmes have General Chemistry in first year. Chemistry-based modules are part of the majority of second year courses. For example, second year students in Biology programmes study a module in Chemical Analysis for Biologists, while second years in the Forensics & Pharmaceutical Science Programme study modules in Inorganic & Physical Chemistry, Pharmaceutical Science (which is largely based on □□Organic

Chemistry) and Analytical Techniques. Forensics & Pharmaceutical Science students continue to study chemistry-related modules in years 3 and 4. The B.Sc. in Drug & Medicinal Product Analysis is the course with the highest number of chemistry-related modules across all four years.

All of the modules have a mixture of lecture, laboratory and tutorial. Again, the hands-on experience in the laboratory is vital for maintenance of the reputation of TUS graduates in industry. In the Programmatic Review, industry stakeholders inform some of the revision of modules to meet industry requirements.

In October 2022 Dr Willie Fitzgerald, one of the original lecturers in chemical instrumentation and analysis retired from TUS. Dr Fitzgerald was a lecturer and course leader in Forensics & Pharmaceutical Science, but taught chemistry and analytical techniques across all courses and levels. He is shown here in the centre of this lab picture.

Science education and outreach at TUS

TUS Limerick is well -known as the venue in recent years for several ISTA conferences and for the ChemEd-Ireland conference, hosted by Marie Walsh and her team. TUS hosts the meetings of the Limerick-Clare branch of the ISTA.

It has also acted as the venue for the annual SciFest competition for the Limerick area. TUS lecturers are involved in organising the annual Limerick Festival of Science for Science Week. TUS participates in the Eurachem Analytical Skills competition for second year undergraduates.

The Department of Applied Science has also been involved over the years in a number of EU-funded science education projects, through Comenius and Erasmus+. These are listed below.

Chemistry is all Around Us Network, (2012 – 2014) https://chemistrynetwork.pixel-online.org/

E-learning from Nature (2016 – 2018) https://enature.pixel-online.org/index.php

MathE (2018 – 2021) https://mathe.pixel-online.org/

FICTION (2018 – 2020) https://fiction.pixel-online.org/

CLIL4STEAM (2019 – 2021) https://clil4steam.pixel-online.org/index.php

GoGreen (2022 – 2024) https://go-green.pixel-online.org/

Marie Walsh has worked closely with Dr Peter Childs since 1988 in producing *Chemistry in Action!* and in running the ChemEd-Ireland conferences on the UL campus until 2007.

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Teaching 21st century science with 21st century skills

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Introduction

In many ways the teaching of science at school and university has not changed much over the years and much of the same core content and practical skills are still taught. Traditional science teaching, at school or university, still in the main emphasises acquisition of scientific knowledge and concepts, and learning laboratory practical skills. Most of this content and the technical skills included in a science course at school haven't changed much in 50 years, although there have been changes in pedagogy. In universities science students encounter the same emphasis on the acquisition of scientific knowledge and concepts, albeit at a higher level, and the mastering of laboratory skills. They may or may not find a change in the way science is taught, and in both school and university the assessment (often terminal and summative), focuses on knowledge and concepts. As a chemistry professor once said: "I tell them, they write it down, and then they give it me back in exams". Too often what passes for teaching is the passage of information from the teacher's notes to the student's notes, without passing through the minds of either of them. If we are honest, that describes our own science education. I have discussed the development of the chemistry curriculum in a recent article (Childs, 2015).

Recent discussions of STEM education have been highly critical of the way science has and is being taught in schools, as both a poor preparation for further study but also as poor preparation for work in the 21st century, and so the call has been for STEM subjects to embrace 21st century skills.

"While scientists passionately explore, reason, discover, synthesize, compare, contrast, and connect the dots, students drudgingly memorize, watch, and passively consume. Students are exercising the wrong muscle. An infusion of STEM taught in compelling ways will give students an opportunity to acquire these active learning skills.

The skills of the 21st century need us to create scholars who can link the unlinkable. ... Nurturing curious, creative problem solvers who can master the art of figuring things out will make them ready for this unknown brave new world. And that is the best legacy we can possibly leave." (Ramirez, 2013)

There have been repeated calls from government and industry and other bodies in many countries for students to be proficient also in '21st century skills', as well as in the traditional technical skills associated with science education. For example:

"We live in a fast-changing world, and producing more of the same knowledge and skills will not suffice to address the challenges of the future. A generation ago, teachers could expect that what they taught would last their students a lifetime. Today, because of rapid economic and social change, schools have to prepare students for jobs that have not yet been created, technologies that have not yet been invented and problems that we don't yet know will arise." (Schleicher, A., 2010)

This comment was made by the Irish Business and Employers Confederation (IBEC) in August 2018 about the Irish Leaving Certificate examination, the terminal state examination taken at the end of formal schooling.

"The workplace of the future will be very different from that of today, with many of the jobs and skills required for future jobs having not yet been established. Irish business values

people with creativity, resilience and aptitude for life-long learning. It is imperative that Ireland's education system equips young people with the skills and knowledge they need to reach their full potential.
"In its current form it is doubtful that the Leaving Cert is in tune with the needs of Irish society and its economy. A high-stakes, terminal exam, predominately based on rote learning and information recall, leaves students with little opportunity to think critically, engage analytical skills and develop greater interpersonal skills.
"It is now time to make the Leaving Cert, and indeed the whole senior cycle and careers service, more relevant for the 21st century. Ibec looks forward to engaging with the National Council for Curriculum and Assessment (NCCA) and other stakeholders on progressing overdue reform.
"To help students transition to future study and into the world of work, we need an education system that encourages a spark for learning, one that creates options for young people and prepares them for the their next phase in life." (McGee, C., 2018)

The problems with science education today

In case you hadn't noticed the world has changed and we have left the industrial age and entered the information age (also known as the knowledge age or the digital age.) People have identified a transition from the 3rd industrial revolution to the 4th industrial revolution. However, in many ways education at school and university is still in the industrial age. What we teach (content), how we teach (pedagogy) and how we examine (assessment), have not changed significantly in the last 60 years or so since I left school (Childs, 2015). There is no shortage of research into each of these areas, but we are still basically working within the same paradigm, tailored to the demands of the industrial age. We have largely failed to adapt teaching and learning to the demands of the information age and are still focusing almost exclusively on content and technical skills. When students leave secondary school at age 18, either for work or further study, they have learned successfully to pass exams but are lacking in soft skills and also in deep understanding even of scientific content, and often with poorly developed laboratory skills. University academics frequently complain that students are not prepared for advanced study in science: in their science knowledge and understanding; in their practical skills; in their mathematical ability and in their study skills. Many universities now have to play catch-up in each of these areas to allow a more heterogeneous student body to progress. When they graduate, students should have a greater and deeper knowledge of science, and be technically proficient in the laboratory, and able to use mathematics in a scientific context. However, their education has still been mostly academic, is focused on technical skills and knowledge, tested by terminal examinations, and rarely includes work experience. When students graduate the almost universal response of employers is that they are not properly equipped or prepared or proficient in suitable soft skills (see Tables 1 and 2). Unfortunately, we are not living in the 19th or 20th century, when our model of science education was developed, but in the 21st century. Our students are now mostly digital natives, firmly in the 21st century, but many of their teachers and lecturers are still in the 20th century.

What are 21st century skills?

There seems to be broad agreement as to what constitute 21st century skills by educators and industrialists. Here is a list of the most commonly identified skills (see also Table 2).

- Problem-solving
- Critical thinking
- Creativity and imagination
- Data interpretation
- Flexibility
- Collaboration and team-work
- Communication skills.

Sometimes, as below, they are summarised as the 4C's or as the 7Cs.

- Communication
- Collaboration

- Critical thinking
- Creativity

Sometimes 3 additional Cs are added:

- Cross-cultural understanding
- Careers and life skills
- Computing and IT skills

Table 1 shows what component skills are associated with each of these seven Cs.

Table 1: The 7 Cs and their component skills
(Adapted from
https://wvde.state.wv.us/instruction/WhyProjectBasedLearningPosting.ppt
ttps://cosee.umaine.edu/files/coseeos/21st_century_skills.pdf)

21st century skill	**Component skills**
Communication and media literacy	Communicating effectively using a variety of media and forms, creating and analysing messages
Collaboration and teamwork	Working with others to create, use and share knowledge, solutions and innovations, involving cooperation, consensus, compromise
Critical thinking and problem solving	Using HOCS to research, analysis, synthesis, project design and management, decision making
Creativity and innovation	Using knowledge and understanding to create new knowledge, designing solutions to new problems, designing new approaches, storytelling and arts
Cross-cultural understanding	Recognising and respecting diversity and difference, and being flexible and ethical in working with others and in different cultures and settings
Careers and life skills	Developing as self-directed, independent, life-long, flexible learners who are honest, and have integrity and an ethical framework
Computing and IT skills	Effective and ethical use of ICT technology to access, organise, evaluate and share digital information, including visualisation skills

"21st century skills" are the skills that today's students will need to be successful in this ever-changing world. The most recognizable of these skills are the 4C's: communication, collaboration, critical thinking and creativity. However, 21st century skills also include social and emotional intelligence, technological literacy and problem-solving abilities. These skills emphasize "application of knowledge" and go beyond rote memorization. Now more than ever, employers are putting an emphasis on these skills as students are entering the workforce ill-prepared. These skills are becoming an important aspect of K-12 curricula. The development of 21st century skills begins in primary school and progresses up through secondary school. The need for 21st century skills has spurred the integration of technology along with the emphasis on STEM and PBL in classrooms. These concepts help students develop the higher thinking skills that colleges and employers are looking for. The education system is changing and placing greater importance on preparing students for the real world, which is why 21st century skills are more important than ever. The definition below from Defined STEM (nd) summarises the need for a change in STEM education. *"Defined STEM utilizes performance tasks, real world videos and project based learning to bring relevancy to the information students are learning. Through these methods of learning students will utilize all 4C's in order to successfully complete their tasks. Furthermore, Defined STEM helps students utilize other aspects of 21st century skills by providing them with digitally based content that emphasizes technological literacy. Through their performance tasks students are asked to use a myriad of skills to complete the assignment at hand. Defined STEM combines multiple subjects into one task and helps the student make real world connections just like they would have to do in college or their future career. Using this cross curricular approach Defined STEM helps students take learning into their own hands and apply what they have learned to the real world."* (https://app.definedstem.com/21st_century_skills)

The World Economic Forum (WEF) in a recent report on the Future of Jobs (World Economic Forum, 2016) collected views on the top 10 skills identified by employers in 2015 and in 2020 (Table 2). The lists overlap and differ mainly in the order. **The key question is whether our science education is preparing students for the world of work.**

Table 2: Top 10 skills needed in 2015 and 2020 (World Economic Forum, 2016, https://www.weforum.org/reports/the-future-of-jobs)

	2015	**2020**
1	Complex problem solving	Complex problem solving
2	Coordinating with others	Critical thinking
3	People management	Creativity
4	Critical thinking	People management
5	Negotiation	Coordinating with others
6	Quality control	Emotional intelligence
7	Service orientation	Judgement and decision making
8	Judgement and decision making	Service orientation
9	Active listening	Negotiation
10	Creativity	Cognitive flexibility

Is it possible to teach science <u>and</u> deliver 21st century skills?

It is clear that the traditional scientific technical skills and knowledge, taught in science education, fall short of what higher education and employers want to see in future students and employees. It is a common complaint that students leaving school have been trained to pass tests, to regurgitate poorly remembered and incompletely understood facts, but with poor laboratory skills, and lacking in communication skills, creativity and critical thinking. In Ireland, at any rate, this seems to be a perpetual complaint from employers commenting on the terminal school leaving examinations. (McGee, 2018)

Students and parents, and even many teachers, see science as a collection of facts to be learned, standard laboratory procedures to be repeated and routine calculations to be practised. The examinations are predictable, and success requires a good memory and lots of practice. The assessment does not encourage real problem-solving or creativity and does not require communication skills or data analysis or interpretation. The existing formal examination system does not assess or reward 21st century skills and thus these are not taught, and students leave school, and often also university, without them.

What would be needed to change the system to deliver 21st century skills alongside and through science education? For them to be effective, the soft skills need to be embedded in science education, not bolted on from outside, so that students leave with an integrated view of technical and soft skills with science content. When we look at the list of what skills are required (Tables 1 and 2), they are actually the skills needed by a scientific researcher and thus should be compatible with the science curriculum. In fact, science should be the ideal curriculum vehicle for delivering 21st century skills, because of the nature of the subject and the fact that it requires cognitive and psychomotor skills, and depends on both mathematics and language as its two supporting pillars. Is it possible to match what we do in science education with what employers look for? Unfortunately, there is often a mismatch between traditional science education and what is required for developing 21st century skills (Table 3).

Table 3: Traditional science teaching and learning approaches compared to teaching and learning for 21st century skills

Traditional	21st century skills
Individualistic competition	Group collaboration and cooperation
Learning facts and concepts	Understanding and applying concepts
Focused on LOCS	Focused on developing and using HOCS
Routine recipe tasks and learning practical skills	Open-ended, inquiry tasks applying practical skills
Following instructions and procedures	Devising experimental procedures
Passive learning	Active learning
Single-answer, algorithmic problem solving	Open-ended problems with several answers
No critical thinking	Develops critical thinking
Didactic teaching and one-way (teacher as guru)	Inquiry-based teaching and interactive (teacher as mentor)
Exam-focused and task-focused	Goal-focused and Skills-focused
Summative assessment	Formative assessment

For example, the school and university system often favour and reward individual competition – who is the best student? 21st century skills needed in the workplace, on the other hand, require collaboration, teamwork and cooperation; it's not about passing exams but about achieving goals. Much of what passes for problem-solving in science education is just routine, algorithmic exercises rather than real problem-solving. Being able to do mole calculations correctly is a skill rarely needed in industry.

Is it possible to match the 21st century skills, which employers want, with the way science is taught at school (and at university)? In fact, many of the required skills have already been used in teaching and learning science, though not always consistently or comprehensively. For example, employers look for collaboration and teamwork as key requirements of employees. Group work and project work in science can deliver these skills, if they are used consistently throughout school and university courses. Communication skills, written and oral, are vital in industry and there is no reason why these should not be developed through science education. The importance of argumentation and discussion in allowing students to marshal and present evidence and to weigh up opposing views is now well recognised. Students need to be given frequent opportunities to practice communication skills in discussion and debate, through producing posters and presentations, by giving talks and writing about science, e.g.

though creating wikis, magazine articles, poetry etc. All these activities have and are being used in science teaching. Project work, in particular, is a great way to synthesise and apply many 21st century skills within a science context, as the success of science fairs shows e.g. SciFest in Ireland. (www.scifest.ie)

Table 4 shows how 21st century skills and existing science activities **can** be matched. There are examples in the literature of science education (research and practice) of all of these activities being used and often used effectively, but it is doubtful if anyone is implementing all of them consistently and progressively through a student's educational pathway. Some are more common in school science courses and others in university science courses. Thomas Friedman (2013) has coined a phrase that a student's passion quotient (P.Q.) and curiosity quotient (C.Q.) are better predictors of success that intelligence quotient (I.Q.) (Friedman, 2013).

Table 4: Matching science education activities with 21st century skills

Science teaching activities	Matching 21st century skills
Discussion and argumentation; presentations; preparing posters, wikis, articles	Communication skills – oral and written, various media
Projects – lab-based and literature- based; design and build; devising solutions to real life issues; mini companies; IBSE	Creativity and innovation
Group work; group projects; mini companies; jigsaw method	Collaboration and team working
Argumentation; analysis and discussion of media; debate Open-ended problems and inquiry activities; PBL	Critical thinking and problem solving
Using IT in research, presentation and communication; e-portfolios Analysis of experimental and other data; using IT skills and software to analyse and present data	Computing and IT skills Data analysis and interpretation
Visits to industry and scientists from industry; project work; work experience	Careers and life skills
History of science; scientific biographies; philosophy of science	Cross-cultural awareness

Not only is much of science education at all levels failing to develop and incorporate soft skills, but formal traditional education is actually actively destroying them. Creativity falls throughout formal education according to a quantitative study by Land and Jarman of 1,600 American children from 5 (98%) to 15 (12%), compared with adults (2%). (Land and Jarman, 1992)

Sir Ken Robinson has a famous TED talk on 'Do Schools kill Creativity?' (Robinson, 2014), to which question he answers 'Yes'. Albert Einstein said: "*It is, in fact, nothing short of a miracle that the modern methods of instruction have not yet entirely strangled the holy curiosity of inquiry; for this delicate little plant, aside from stimulation, stands mainly in need of freedom. Without this it goes to wrack and ruin without fail.*" An increasing focus on tests and external exams and learning outcomes has narrowed the curriculum and learning experience, and resulted in rote learning and memorisation and exam technique. Teaching to the test has resulted in a decline in critical thinking, creativity and other soft skills. The test-based school system favours individual competition over collaboration and cooperation. Student-centred group work and inquiry in primary schools often leads to teacher-centred, individual study and didactic teaching in secondary school.

Examples of good practice

It is an educational fallacy that process matters more than content, and skills more than subject matter. As science teachers we believe that content is important, but it is not the only thing that matters. 21st century skills must be grounded in subject content, as they are the means and vehicle by which students can learn and understand the content, and also develop the skills to use and apply their knowledge. The pedagogical methods used in science teaching must be chosen to develop 21st century skills through subject content and classroom and laboratory experiences. Here are some of the key design principles of such a science course:

1. *Connect content knowledge to real world situations and problems so that students experience science as authentic and life-related.*
2. *Emphasise the development of deep understanding though tackling problems and projects and working with others.*
3. *Encourage students to think about their thinking through metacognitive activities and reflection.*
4. *Provide technology to help students access, organise, evaluate and share knowledge and choose suitable ICT tools for specific tasks.*
5. *Allow opportunities for students to become creators and innovators through projects and collaborative activities.*
6. *Engage and stretch students by providing complex and challenging problems that require higher order cognitive skills, access to information and practical skills, and working collaboratively.*
7. *Facilitate collaborative and cooperative work in a variety of contexts and projects.*
8. *Develop career and life-skills by encouraging self-directed and independent learning, making contact with different work environments and enabling relevant work experience.*
9. *Help students develop an ethical framework for decision making and good practice, and help them to become flexible life-long learners, who can make connections with other subjects, concepts, cultures and environments.*(Beers, 2012)

"The keys to integrating 21st century skills into the classroom are application, connections, and participation." Sue Z. Beers (Beers, 2012)

Barriers to change

The way science is taught in many countries in terms of content, pedagogy, assessment and skills does not produce or match the demand of industry and society for 21st century skills, relevant to the fourth industrial revolution. To deliver 21st century skills through and with science education requires change: a change in the content, pedagogy, assessment and in the pre-service and continuing professional development of science teachers. Change is always difficult and takes time, commitment and resources. There are also barriers to change within the education system and from teachers and parents. The change from a traditional subject knowledge-centred curriculum to learner-centred and skills-centred curriculum is challenging, as this takes many teachers out of their comfort zone and requires changes in pedagogy and assessment, if not in content. The science curriculum and assessment are usually centrally controlled and teachers only have control over how they teach. Most teachers and lecturers will have been exposed to traditional science education and may not have experienced or be proficient in soft skills. The following passage describes some of these problems and barriers to change.

"There have been a great many attempts to reform the curriculum, particularly over the last 20 or 30 years. These attempts have mainly focused on making the curriculum more 'learner-centred' – that is, more appealing to - or 'inclusive' of - students from a wider range of backgrounds; more 'relevant' to students' existing experiences, interests and background knowledge; more connected to authentic, 'real world' contexts; and/or more cognisant of what we know about how people actually learn new things. However, while this work (sometimes) resulted in the appearance of new words in official curriculum documents, it has had very little effect on the way science is taught in schools.

Secondary school science programmes largely continue to teach conceptual knowledge in discrete disciplines, while in primary schools science has a low profile, appearing mainly as a topic or context for inquiry learning. The traditional model persists for a number of reasons. Most secondary science teachers support it because their early enculturation through school and undergraduate study has fostered a commitment to and identification with this type of knowledge, and because their existing skills and professional identities are oriented towards the traditional curriculum. It is also maintained by existing resources such as textbooks and laboratories; by school structures such as timetable arrangements and assessment traditions; by many academic scientists and science education academics; and, by the traditional high status conferred on highly differentiated, insulated school subjects like science. The most recent official national curriculum [in New Zealand] provides a number of signals for change and gives schools considerable freedom to make decisions about how it is best implemented in their community: however, these signals are seldom, as yet, being taken up. What all this tells us is that understanding what good science education looks like – that is, science education that is educative, that represents science accurately, and that is engaging for students – is very challenging, and that, despite much effort, it continues to be very challenging." (Gluckmann, 2011, p.25)

We could summarise the main factors which determine the possibility of change towards skills-based teaching and learning as:

- The education (pre-service and in-service) and expectations of science teachers,
- The demands and traditions of the science curriculum,
- The resources used (books and laboratories),
- The teaching methods used,
- The assessment (especially if a formal, national assessment),
- The external demands of higher education, parents, employers and society.

To move towards delivering 21st century skills through school science education will require major change in each of these areas.

Examples of integrating 21st century skills into STEM education

a**) Examples from second level education.**

i) The New Irish junior cycle course

A new Junior cycle course (age 12-15) is being introduced in Ireland based around a set of principles and key skills (Figure 1). The new science specification was started in 2016 and will be examined for the first time in 2019.

Figure 1: Key skills for the new Irish junior cycle (https://www.ncca.ie/en/junior-cycle/framework-for-junior-cycle)

The important aspect of the new Framework for Junior Cycle is that it aims to integrate subject content with key skills, many of which are 21st century skills. The course also emphasises continuous formative assessment as well as a terminal examination.

ii) **Concept schools in the USA**

A network of 30 schools focusing on STEM (science schools) and integrating 21st century skills into their programmes, as described below.

"STEM education is not the panacea for all the world's problems and this nation's economy, but it is a step in the right direction. In the 30 STEM-focused, college-prep schools in the Concept Schools network throughout the Midwest, there is an emphasis on 21st-century skills and strong character development." (http://www.conceptschools.org/employers-want-stem-skills-and-soft-skills-weve-got-them/)

b) Examples from university (third level) education.

i) RSC transferable skills resources

The Royal Society of Chemistry in the UK has been promoting transferable skills for chemistry graduates for several years as part of their chemistry degree studies. They have produced a booklet on 'Key Skills for scientists: getting the message across' (http://www.rsc.org/learn-chemistry/resource/res00001029/key-transferable-skills-for-science-students?cmpid=CMP00001721) and also a downloadable Undergraduate Skills Record (https://www.rsc.org/cpd/undergraduates) for students to fill in during their course.

ii) **University of York YouTube videos**

As part of a module on polymers, students are given an option of making a YouTube video or writing a magazine article. Out of a class of 180 students, 35 chose to make a video. *"When surveyed, these students also fared higher in terms of their ability to recall chemical concepts and scored higher in terms of their engagement with and enjoyment of the course."* (Seijo, 2014)

c) Problem-based learning at University of Reading

Using PBL to develop skills for work through a first-year undergraduate chemistry module. *"A new first year module was planned with aims to:*

- *Introduce students to open and closed types of problems and help them develop strategies for tackling them.*
- *Help students develop independent study skills so they can research a topic, process the information and solve a problem based on it.*
- *Help students develop time management, organisation and team-working skills.*
- *Give students practice and support in written and oral communication and help them develop good scientific writing skills."* (Page, 2013, p. 22)

Recommendations and strategies

Firstly, recognise the importance of 21st century/soft/transferable skills for our students.

Secondly integrate the teaching of science at second-level and third-level with the development, consolidation and improvement of soft skills as students progress through the education system and enter the world of work.

Key ways of doing this should include:

a) Group work;
b) Project work (individually and in groups);
c) Inquiry-based practical work to develop research skills;
d) Opportunities to develop communication skills (written and oral);
e) Frequent use of ICT integrated with other activities;
f) Work experience to give real life platform for soft skills;
g) Activities to develop critical skills and cognitive acceleration;
h) Integrate maths into science teaching including analysis, estimation of errors and presentation of data.

One good idea is to create personal e-portfolios summarising student work and achievement and a record of skills development, see the RSC Key Skills for Scientists and the Undergraduate Skills Record (https://www.rsc.org/cpd/undergraduates). A check list of soft skills can be used across modules at third level or across topics and subjects at second level, to ensure that soft skills are covered and revisited throughout a student's career. Project work, either literature-based or lab-based, is ideal for integrating a number of soft skills into a science course and invariably project work enthuses and motivates students.

Conclusion

"Exemplary science education can offer a rich context for developing many 21st-century skills, such as critical thinking, problem solving, and information literacy. These skills not only contribute to a well-prepared workforce of the future but also give all individuals life skills that help them succeed." (NSTA, 2011)

The traditional way that science is taught and assessed, and the way teachers are trained, does not produce, in most cases, students and teachers who are equipped with 21st century skills. As a consequence, students are not properly equipped either for further study in science or to enter the workforce in a knowledge economy, which is rapidly moving into the age of the fourth industrial revolution. In many cases we are doing what we've always done and science education in 2022 is not much different in many countries from that in 1972 or even 1922. But the world has changed and is changing faster than the educational system can keep up.

All science education is based on and depends on the 3Rs, without which no progress or real learning can occur: reading, writing and mathematics. A useful image that has been developed is the learning equation:

3Rs times 7Cs = 21st century skills

Others have added three further Rs: risk-taking, resilience and reflection and 3Ms: motivating, meaningful and made-for everyone. This may become a confusing alphabet soup, but the science teacher can recognise the importance of each of these skills and their relevance to science teaching. The challenge is to take what we already know, to implement successful methods and approaches based on science education research, and to integrate 21st century skills with our 20th century skills.

This call for 21st century skills is definitely in fashion and in tune with the spirit of the times, but it has also been criticised as being a new setting of an old tune, which many would claim has failed in the past, of process over content, skills over subject knowledge (Ravitch, 2015).

"For the past century, our schools of education have obsessed over critical thinking skills, projects, cooperative learning, experiential learning, and so on. But they have paid precious little attention to the disciplinary knowledge that young people need to make sense of the world.

This deeply ingrained suspicion - hostility, even - towards subject matter is the single most significant reason for the failure of the standards movement in American education over the past generation.

We should have been educating future teachers to study their subject or subjects in depth. We should have paid attention to what Lee Shulman, educational psychologist and professor emeritus at Stanford, calls "pedagogical content knowledge." We should have been helping teachers determine ways to light up young minds and to generate excitement about historical imagination or scientific discovery."

I would agree that, as scientists and science teachers, our subject is of paramount importance. I am **not** saying that we should favour process over content, or soft skills over technical skills, or theory over practical work; what I am saying is that we should modify our pedagogy and our assessment in order to build soft skills into our teaching of science. The result will be that our students come out of school or university more employable, with a broader set of skills than just being technically competent. Our aim must be high quality STEM education **together with** embedded and integrated soft skills. As we live in the knowledge and digital age and enter the fourth industrial revolution, we do our students a disservice if we do not allow them to develop 21st century skills alongside their technical skills. They need, our society needs, and their employers need, excellence in both of these areas. This extract on *'21st Century Skills: Preparing Students for THEIR Future'* is a good summary of where we should be heading.

"Instruction that meets the needs of today's students will incorporate:

- *A variety of learning opportunities and activities*
- *The use of appropriate technology tools to accomplish learning goals*
- *Project- and problem-based learning*
- *Cross-curricular connections*
- *A focus on inquiry and the student-led investigations*
- *Collaborative learning environments, both within and beyond the classroom*
- *High levels of visualization and the use of visuals to increase understanding*
- *Frequent, formative assessments including the use of self-assessment.*

*The role of teachers in a 21st century classroom shifts from that of the "expert" to that of the "facilitator." The focus for instruction shifts from "knowing" to being able to use and apply information in relevant ways. Students who are being prepared for the 21st century will be involved in "continuous cycles of learning" (Lemke, et al, 2003) that lead to deeper understanding of the subject area content and that develop the critical skills for meeting the challenges of the future.***"** (Beers, 2012)

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Biography

Dr Peter Childs retired from the Dept. of Chemical Sciences at UL in 2009. He started Chemistry in Action! in 1980 and the ChemEd-Ireland series of conferences in 1982. He is a former President of the ISTA and of the Institute of Chemistry of Ireland and was chair of the EuCheMS Division of Chemical Education from 2002-2008. This talk was originally given at a conference in Haifa, Israel in 2019. Versions of this talk have also been given at the Eurovariety and iVICE conferences.

The Story of the Atom

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Introduction

As chemistry teachers, and chemistry teacher educators, we work as translators, interpreters and communicators of science [the natural sciences, often called the *hard sciences*] to young people. We can describe our work as a process of policy enactment of nationally desired reforms, such as improving science literacy across the curriculum, for helping young people to learn how to live well in a highly scientific and technological world.

Chemistry teachers and science educators work in intelligent and ethical practices, constantly engaged in a dynamic interplay between scientific knowledge and theory [disciplinary and theoretical knowledge], ethics and other ways of knowing, such as everyday knowledge. This complex interplay between knowledge, theory, ethics and experiential practice is at the heart of all good teaching and is often referred to by the term *praxis* (Mooney Simmie, Moles and O'Grady, 2019). If you want to read more on this, can I recommend the work of the sociologist of education Stephen J. Ball at the Institute of Education, University of London and the work of the philosopher of education Gert J. Biesta, a visiting Dutch professor at NUI, Maynooth (Ball, 2008; Biesta, 2016).

In this article, I want to share with you 'The Story of the Atom' and to direct you to some interesting 'Readings and Resources' that will help up-skill your content knowledge, and invite you to seek better ways of communicating science to all young people.

The Study of Chemistry

Chemistry is a study of matter and energy at the level of atoms and molecules. The study is elegant and when understood at a deep level it can be seen as highly organised, logical and powerfully predictive. However, the problem always for the chemistry teacher, and science educator, is how to teach the big ideas and concepts in chemistry - with their strong focus on rules and complex abstractions - in ways that invite interest and engagement from all students. And not only those students who grasp everything immediately! For that we rely on the teachers' professional judgement in knowing where to draw the line between spontaneity and structure in the chemistry classroom and laboratory. Teaching that has an inquiry-orientation, and also connects to the lives of students and their cultural contexts.

The Story of the Atom

The story of the discovery of the structure of the atom has been for the most part unearthed by physicists, with the exception of the English chemistry teacher, John Dalton. Models have been formulated, proved and disproved through the years and in ways that hopefully reveal to you the importance of thinking and the value of thinking outside-the-box, making educated guesses, having hunches, using imagination and innovation, creativity and keeping an open mind and the inherent danger of foreclosure in all things scientific and educational.

How you decide to delve into this story with your students, and the lessons to be learned from this story, I leave in your capable hands. Here I will chart some key thinkers and experiments that advanced the structure of the atom to where we are today.

The Early Greeks

The story of the atom is more than 2,400 years old! The story generally begins with the early Greeks and with Democritus in 400BC. The early Greeks thought that chemistry was connected to the four elements of air, water, fire and earth. We often hear this thinking dismissed but there is another way of reading this! If you open any high school or secondary school chemistry text, in any part of the world, you will find yourself introduced to something about the chemistry of the atmosphere [air and air pollution]; the chemistry of water [water treatment]; the chemistry of fire [combustion chemistry] and the chemistry of the earth [material chemistry]. It seems as if it might be foolish to dismiss the thinking of the early Greeks, to give them more credit and to suggest maybe that all that was wrong here was a problem of nomenclature, the correct naming of what they were suggesting!

This is an opportune place to recommend to you a new chemistry book, by Kennedy and O'Connell (2022) published by Folens and part of a new series of books for Transition Year called *Bridge the Gap.* The table of contents invites you to study the Chemistry of the Atmosphere, Environmental Chemistry; Water in the World, Forensic Science etc. I rest my case about these early Greeks and their contribution! Another new book, published in the US, that has a freshness about the title is one by Greer (2022) that is called *Chemistry for Cooks* and claims to use a fun approach to teaching the principles of science. Might be worth a read.

Back to the early Greeks! Democritus theorised that matter could be divided and sub-divided, sliced and diced, until eventually one arrived at a 'point' where matter could no longer be divided into smaller and smaller pieces. For example, if you take a bar of gold, you can imagine slicing and dicing this bar until eventually there would be an infinitesimally tiny piece of gold that could no longer be sub-divided any further. He called this last tiny piece the 'atom', meaning 'indivisible'. Today we know that he was both right and wrong! He was right in that atoms today are understood as the building blocks of chemistry. There is therefore something about them that suggests to chemists they cannot be sliced any further without changing their properties to something else. However, we also now know that the atom can be 'split' into smaller sub-atomic particles and that the atom itself can undergo splitting of its central core, the nucleus [nuclear fission]. However, if the atom is split it is fundamentally changed to a different substance. Good old Democritus, what a clear thinker and better yet that he lived at a time when people clearly listened to him, before they waited to see solid proof of his 'atom' with the naked eye! A wait of 2000 years!

First Proof of the Atom

After the early Greeks, the next significant milestone in the story of the atom is found in the early 19th century in Britain. It is here, especially in the intervening years between the mid-1800s and the mid-1900s that most theoretical and experimental work was done to lay the foundation of the scientific knowledge we have today of the structure of the atom.

We begin with the English chemist, and chemistry teacher John Dalton [1766-1844], who provided the first real proof of the existence of the atom [in 1803], from his theorisations, observations and laboratory experiments. Dalton left a vast library of chemistry writings on the atom, he devised an intricate series of hieroglyphics (symbols) to depict the atom and started to organise atoms of different elements. What is most amazing about this complex system is the uncanny resemblance of his drawings of the atom to the first electron tunnelling microscopic images of the atom in the early years of this century. His work increased the status of chemistry and moved it into a new place in the academy as an exact science.

Discovery of the Electron and the first Atomic Model

The story of the atom then moves to the English physicist, J.J. Thompson [1856-1940], who conducted experiments in a sealed glass tube with charged plates, a cathode ray tube [as used in early television sets]. With this experiment, he discovered the existence of negatively charged particles in the atom that he called electrons. He formulated the first atomic model, which became known as the plum pudding model of the atom, showing negative electrons inside his atomic model in much the same ways as raisins can be dispersed inside a pudding. He explained the neutrality of atoms through depicting this negative charge positioned in a sea of positive charge. He won the Nobel prize for physics in 1906.

Discovery of the Nucleus and the second Atomic Model

Shortly after the discovery of J.J. Thompson's plum pudding model of the atom, a New Zealand scientist, Ernest Rutherford [1871-1937], working in the Cavendish Laboratory in Cambridge with Hans Geiger, conducted what is now called the Gold Leaf experiment.

Rutherford had a fascination for scientific investigation that was tempered by a need for solid proof. He was working on a study of radioactivity and advancing a concept of the nuclear atom. He was to make a fascinating breakthrough in the understanding of the structure of the atom, a discovery that was to disprove the plum pudding model of the atom.

Rutherford used an alpha-particle emitter, to fire alpha particles at thin gold leaf. He measured the scattering pattern of the particles coming onto a screen. The particles were fired through a narrow opening in what was an almost circular screen.

If the atom was a dense plum pudding, with negative particles embedded in a sea of positive charge, as Thompson had predicted, Rutherford would have expected the scattering pattern to show this. Instead, he was alarmed to find the scattering pattern showing up in places where he least expected it, with some scattering coming straight back to him. He remarked at the time that it was like firing a 15-inch shell at a piece of tissue paper and it bouncing back to hit him! His experiment provided solid proof that the atom was mostly empty space and had a small dense nucleus at its core. The electrons orbited at some distance from this nuclear core. He had disproved J.J. Thompson's plum pudding model and laid claim to what was now Rutherford's planetary model of the atom – a nucleus of positive charge surrounded by orbiting negatively charged electrons, in a motion much like the earth and the planets orbit the sun.

The most familiar model of the atom

As time went by, and as scientists discovered more about the sub-atomic structure of the atom, they began to map out a new model of the atom, that surpassed the earlier models of Thompson and Rutherford. James Chadwick [1891-1974] was credited with discovery of the neutron in 1932, a neutral particle found in the nucleus of the atom.

Chadwick was working on a study of radioactivity in Rutherford's physical laboratory, now in Manchester. He conducted the first ever artificial transmutation of an element [nitrogen] with the subsequent release of a proton and a vast amount of energy. This experiment was to be a precursor to the study that led in the US in the 1950s to the atom bomb. He received the Nobel prize in physics in 1935.

It was now known that the atom was composed of a nucleus at its core, containingsub-atomic particles, positive protons and neutral neutrons. This positively charged core was surrounded by negatively charged particles called electrons, moving around the nucleus in definite energy levels called orbits, and held together by the forces of attraction found between oppositely charged entities. The mass of the atom was concentrated in the core. Stable atoms held equal numbers of protons and neutrons. You could add an extra neutron, or more, and get isotopes of the same atom. However, if you changed the number of protons you were no longer referring to the same atom.

A picture of the atom was starting to emerge. The Bohr model of the atom is the one we are most familiar with today. It is a model for which the Danish physicist Niels Bohr [1885-1962] won a Nobel prize for and works as a good-enough, simple model to introduce students to the atom.

But, just as you might have guessed this good - enough model of the Bohr atom is far from accurate and there is yet again another chapter in the story of the atom.

Structure of the Atom today

Until the 1980s, and the early years of this century, the Bohr atomic model held a central position in school-based chemistry texts. As scientists continued to piece together the behaviour of matter, molecules and energy, new findings started to emerge. A far more sophisticated picture of the atom was beginning to emerge. The changing landscape was heavily influenced by breakthroughs coming from better microscopic instrumentation and a branch of physics called Quantum Theory, a theory that was challenging classical physics and was asking new questions about matter and energy.

The negatively charged electron was now understood to possess a wave-particle duality, and it could be considered to be a particle and a wave at the same time – a view from Quantum Theory. In addition, the formulation by Heisenberg of his Uncertainty Principle, showed that while one might be able to measure the mass of a moving particle [e.g. an electron], it would not be possible, at the same time, to measure its velocity [speed in a stated direction].

These new theories and postulates [quantum theory, Heisenberg's Uncertainty Principle] showed chemists that the best they could do when trying to locate exactly where the electron was at any point in time inside the atom [where is it?], was to locate the probability of finding it at any given place. It was over to the physicists, especially Schrödinger, to work out the mathematical equations and the subsequent shapes of these orbitals of probability.

What emerged were new fuzzy pictures showing the electrons moving in definite shells/orbits inside the atom, behaving in much the same way as a swarm of bees hovering around a hive. These fuzzy orbitals were of different shapes and represented different energy levels, depending on their distances from the nucleus, e.g. spherical s-orbitals and dumbbell-shaped p-orbitals.

Today, with high resolution electron tunnelling microscopes images of the atom can be seen. They have an uncanny resemblance to the drawings by Dalton in the early 1800s. The orbital shapes depict the probability of finding an electron, in a designated energy level, and at a certain distance from the nucleus. The provide the chemist today with vast amounts of information about the properties and potential chemical reactivity of each atom.

If we were to imagine Croke Park as the size of the atom, then the central nucleus of an atom would be located in the middle of the pitch, and would be the size as a garden pea [a tiny speck]. The electrons orbit this nucleus as negatively charged particles positioned in definite orbitals/energy levels and, at the same time as waves of probability [wave-particle duality] that take on distinct shapes, e.g. s-, p- and d-orbitals.

We now have a detailed model of the 21st century atom, far more nuanced and fuzzy than Bohr's atomic model. However, what the story tells us so far is to *Watch This Space*! While we have a good grasp of the structure of the atom today, with better instrumentation and new creative thinking into the future there is clearly more to come!

Readings and Resources

Don't forget to register with EPI•STEM to access our growing library of on-line CPD resources for Science and STEM teachers, such as podcasts and booklets in our new *On-line EPI•STEM Academy of STEM Teachers*. We want to acknowledge the HEA performance fund 2020-2022 to get this academy started. Please contact Helen Fitzgerald, Senior Executive Administrator of EPI•STEM for further information, Helen.Fitzgerald@ul.ie.

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Highly recommended U-Tube video clips
CaSTL CENTER Chemistry at the Space-Time Limit is a National Science Foundation Centre at the University of California . "What is the Atom and How Do We Know? Stated Clearly was narrated by Jon Perry, has 2.3 million views, takes 12.15 minutes. 18th Sept 2018
[What Is An Atom And How Do We Know? – YouTube]

"A Better Way to Picture Atoms", 19 May 2021
https://www.youtube.com/watch?v=W2Xb2GFK2yc
3.2 million views and takes 5.35 minutes.

□

Biography

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Student Engagement Using Online Tools with Science Students in TUS

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Introduction

The academic years 2019/2020 and 2020/2021 were profoundly impacted by the Covid-19 pandemic causing a sudden migration to online teaching. This was a very stressful time for all involved and most welcomed the opportunity to return to the in-class environment and the advantages this offers compared to purely online. However, this disruption also offered an opportunity to appraise online teaching tools especially for any benefits they may offer as part of a blended curriculum in the future.
This opportunity was the motivation for me to carry out a research PhD into the effects of online tools on student engagement of science students in TUS, but more about that later. First, we need to consider what is meant by the term "student engagement".

Student Engagement

The term student engagement has been *"used to refer to so many different things that it is difficult to keep track of what people are actually talking about" (Gibbs, 2014)* . As this quote shows simply saying you are looking at student engagement is not enough, you need to define what you mean by student engagement. Student engagement can be roughly divided into two broad categories, as either an accountability measure of student's involvement or as a variable in educational research, that can be linked to predicting student behaviour (Axelson & Flick, 2010) .

If you are looking at student engagement from an administrative point of view you might for example, simply be talking about attendance figures. Alternatively, if you are looking at student engagement in the classroom, you may be more concerned with whether students are interacting with the material they are being taught.

For clarity, it is the second of these we are concerned with here, but further demarcation is needed to give a more complete picture of student engagement and that's where domains and frameworks of engagement come in.

Domains and Frameworks of Student Engagement

Student engagement is often viewed as consisting of separate, but interrelated domains with the most broadly utilised being the three-domain model shown in Figure 1 (Fredricks *et al*., 2004). A framework such as this can help when it comes to assessing Student Engagement.

Behavioural engagement can be viewed as students' level of activity in class, through attendance, participation and interaction with activities. This is relatively easy to measure as it could simply involve observable measures, such did the student attend class or did they complete the quiz they were given in class/online?

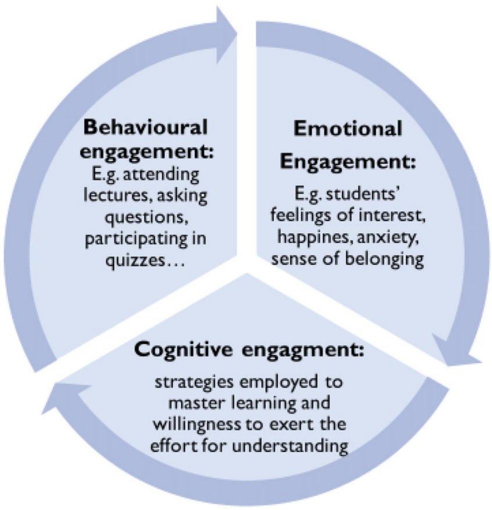

Figure 1: Three Domain Framework of Student Engagement (Fredricks et al., 2004)

Cognitive engagement is associated with the students' interaction with content and their understanding of it. To measure this, it is necessary to gather some responses from the students through surveys or interviews, to ascertain whether they thought they understood the subject matter any better after attending the class or doing the activity you gave them.

Emotional engagement is concerned with how students feel about their studies, such as for example whether they are happy or anxious in class. Again, this can be assessed by asking the student how they feel about carrying out an activity. Do they want to be in class? If not, why not? Perhaps they may not feel like they belong? The reasons behind these emotions may be complex and not solely related to the academic exercise.

While the framework in Figure 1 (Fredricks et al., 2004) has proven very popular, there are many other Student Engagement frameworks out there.

A framework specific to online delivery (Redmond *et al*., 2018) shown in Figure 2, contains social and collaborative domains in addition to the behavioural, cognitive and emotional domains. The indicators in Table 1, give some detail on how these domains differ from each other.

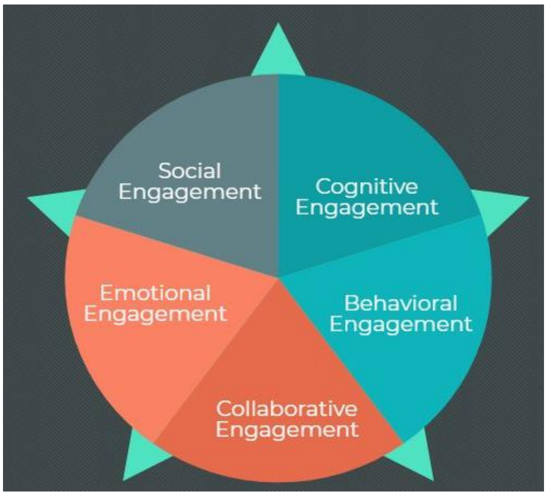

Figure 2: Online Engagement Framework for Higher Education(Redmond et al., 2018)

Table 1: Illustrative Indicators for Online Engagement Framework for Higher Education (Redmond et al., 2018)

Online Engagement Element	Indicators (illustrative only)
Social engagement	Building community Creating a sense of belonging Developing relationships Establishing trust
Cognitive engagement	Thinking critically Activating metacognition Integrating ideas Justifying decisions Developing deep discipline understandings Distributing expertise
Behavioral engagement	Developing academic skills Identifying opportunities and challenges Developing multidisciplinary skills Developing agency Upholding online learning norms Supporting and encouraging peers
Collaborative engagement	Learning with peers Relating to faculty members Connecting to institutional opportunities Developing professional networks
Emotional engagement	Managing expectations Articulating assumptions Recognising motivations Committing to learning

It could be argued that there is significant overlap between the social and collaborative domains. Indeed, there are four domain frameworks that conflate the social and collaborative into a single social domain (Bowden *et al*., 2021).

Not only are social and collaborative domains so closely related that different frameworks may or may not distinguish between them, but a recent study of chemistry students found that they do not readily distinguish between behavioural and cognitive engagement (Naibert & Barbera, 2022).

In addition, it is important to point out that individual domains can impact on each other (Philp & Duchesne, 2016). For example, if students are so cognitively engaged that they want to "solve the puzzle", this could lead to increased behavioural engagement as they keep working until they do. Alternatively, this focus on this one task could also lead to them neglecting to attend to other tasks, i.e. inhibiting behavioural engagement.

Similarly, social engagement can be influenced by emotional engagement. For example, if the student enjoys working with others, social engagement may be enhanced. On the other hand, if there are issues between individuals working as a group this can inhibit social engagement.

While all of this might seem to paint a somewhat confused picture, the reality of student engagement can be quite messy. Accepting these complexities and embracing them can hopefully lead to a deeper understanding of student engagement.

Finally, just to add to this complexity, it is important to acknowledge some other factors, outside of our control, that can affect student engagement. As alluded to earlier, when describing the emotional domain, student engagement may not just be affected by what goes on within the classroom (be that a physical space or a virtual environment) but also by the broader sociocultural environment our students exist within (Kahu, 2013). The revised model of a framework which accounts for these external factors is shown in Figure 3 (Kahu & Nelson, 2018).

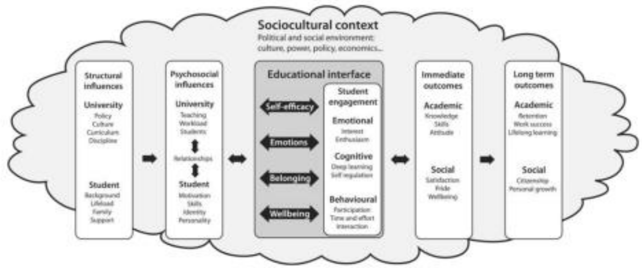

Figure 3: Refined conceptual framework of student engagement incorporating the educational interface (Kahu & Nelson, 2018)

Situating the educational interface within the broader sociocultural context is true to the reality of student engagement, but while it is good to be aware of these broader factors, it is within the educational interface that we influence student engagement through our pedagogies.

Initial Research & Findings

Ella Kahu, who developed the framework shown in Figure 3, recommends that future research in the area should concentrate on qualitative research in individual institutions (Kahu *et al.,* 2020). Considering this and other factors, an explanatory. sequential design. mixed methods study, with an emphasis on the qualitative (Creswell & Clark, 2017), was decided on for this research into the effects of online tools on Student Engagement of science students in TUS Midwest.

The first data collected was from focus groups with TUS academic staff, on their views on how online tools affect student engagement. This data was subject to a thematic analysis (Braun & Clarke, 2022).

The thematic analysis process involved assigning codes to the focus group responses and grouping these codes into interrelated themes that summarised the academics experiences. The resultant thematic map is shown in Figure 4.

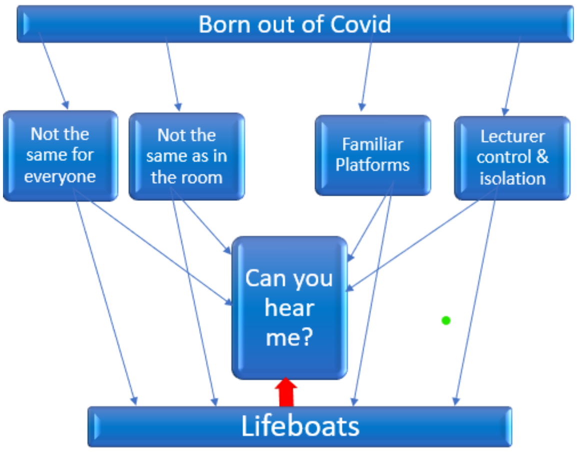

Figure 4: Thematic Map from Academic Staff Focus Groups

The overarching theme in this analysis is "Can you hear me". This encapsulates the issues that academic staff had communicating with students online. This overarching theme can be seen to arise out of the four sub-themes shown in Figure 4, while these in turn arose from the initial theme of "Born out of Covid". It is important to acknowledge that academic staff contributions to these focus groups were very focused on their own experiences of Emergency Remote Teaching (ERT) during the pandemic.

On a more positive note, these focus groups also provided numerous examples of the strategies that academic staff employed to reach their students during ERT. These are identified as "Lifeboats" in the thematic map, as they were built out of the difficulties encountered and then used to counteract the main "Can you hear me" theme.

Future Work

What is missing from this thematic map is any reference to the engagement domains in the frameworks outlined earlier. A further thematic analysis of the data is planned to make these connections.

In addition, as this research project progresses, changes will be made to teaching practice to incorporate online tools and then assess their impacts on student engagement. To give you a flavour of what this involves, student interviews are currently being conducted into student experiences of using Moodle Workshop to conduct peer review as part of a group assignment. Moodle is the Virtual Learning Environment (VLE) used extensively in TUS and the Workshop function within it allows students to anonymously share rough drafts of their work and give each other peer feedback, before submitting their assignments.

The next phase of this research is currently intended to carry out a similar investigation into the use of Vevox during face-to-face lectures. Vevox is software that allows the teacher to gather anonymous responses from students live in class. The students use their phones to answer questions, express opinions, etc. and these anonymous responses can be collated and shared with the class as a whole during the lecture session and/or uploaded to the VLE for the students to access later.

Reflection

Using technologies such as these during online classes, when students were confined to their own homes and unable to physically meet up with their classmates, was an obvious benefit, but are these technologies still be useful in a post-pandemic context? Will they still benefit students now that they can interact face-to-face, as they used to before March 2020? Can we use it in a blended approach that is an improvement not only on pandemic era ERT, but also on pre-pandemic teaching?

All of these are questions that this research hopes to provide some answers to. Perhaps you have your own questions pertinent to your own teaching practice? It is hoped that the content of this article may prompt these, and that the theory provided within the engagement frameworks and the domains contained within them, may provide you with some perspectives to help you find the answers to these questions.

Acknowledgements

Special thanks to my project supervisors Dr Barry Ryan (TU Dublin), Prof Michael Seery (Cardiff Met) & Dr Ann Murphy (TUS) for all their assistance with this research. Thanks also to the TUS academic staff who contributed to the focus groups.

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Biography

Billy Madden is a science lecturer in TUS Midwest with close on 30 years teaching experience on the Moylish campus. He has an MA in Teaching & Learning from WIT and is currently undertaking a PhD on the impact of Online Tools on Student Engagement of Science Students in TUS.

Research-informed adaptations to school practical work

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Why do we do practical work?

Practical work describes whole class hands-on laboratory tasks during which students, manipulate materials, make observations, and reproduce phenomena (Abrahams & Millar, 2008). Many teachers of chemistry value hands-on practical work as a means of engaging students and making chemistry come alive.

"Chemistry is necessarily an experimental science; its conclusions are drawn from data, and its principles supported by evidence derived from facts" (Faraday, 1827 p.b).

In England, the exam boards set out the apparatus that students should use and the techniques they should develop. The students' practical skills are assessed in the terminal exams, which contain questions that specifically draw on the experience students have gained from doing practical tasks. Schools are encouraged to include "purposeful practical activities" as part of the day-to-day teaching and learning. Purposeful practical activities are defined as those in which the teachers know the purpose of the activity, *"and it should be planned and executed so it is effective and integrated with other science learning"* (Gatsby, 2017, p. 45). The Assessment and Qualification Alliance (AQA) exam board states that by *"focusing on the reasons for carrying out a particular practical, teachers will help their students understand the subject better, to develop the skills of a scientist and to master the manipulative skills required for further study or jobs in STEM subjects"* (2019, p101).

Working memory and practical work

Human cognitive architecture is made up of the long-term memory, which can store very large amounts of information, and the working memory, which is limited by both its capacity and its duration. Indeed, the working memory has been described as 'the limited mental "space" in which we think' (Clark, Kirschner, & Sweller, 2012, p. 8), and is roughly equivalent to what humans are conscious of at any one time. Cognitive load is the term used to describe the demand placed on the working memory by a task; when the load becomes too high, learning is impaired (for a comprehensive and open access overview see Sweller, van Merriënboer, & Paas, 2019).

School practical work has been described as "cookbook" or "recipe following" (Clackson, & Wright, 1992) with task completion at the forefront of students' minds. If practical work is to meet the expectations previously described, then the learners must have both hands-on and minds-on (Abrahams, & Millar 2008). This disconnect between objectives and outcomes has been attributed to the learner's working memory becoming overloaded by the task, which leaves little or no space for thinking beyond immediate actions (Johnstone & Wham, 1982).

Pre-laboratory preparation

Pre-laboratory preparation refers to the practice of providing learners with an activity to complete that builds familiarity with the conceptual procedural knowledge required by a practical task. Before our students undertake a practical task detailed by the exam specification, they are asked to watch a video or simulation about the task as homework. This is done to try to reduce the amount of new information students are being exposed to in the laboratory. Introducing students to the equipment and lab protocol aims to remove some of the cognitive load imposed by performing the experiment. We have found that practical lessons are more efficient when the students come preprepared, which is vital as limited teaching time prevents repeated attempts to complete the same task. (See Hennah, 2019).

Collaboration and practical work

Researchers have found that laboratory work can function as an active learning environment if students are provided with time to talk and discuss what they are doing (Lunetta, Hofstein, & Clough, 2007). Language is a communicative tool used by and between people to make meaning, Vygotsky's sociocultural theory understands that knowledge is not transmitted from one individual to another but co-constructed through social interaction (Vygotsky, 1978). When working together, students not only interact, they 'interthink' (Littleton & Mercer, 2013). The use of language and other modes of representation enable learners to link their individual minds to create a more powerful information-processing system, which Mercer (2013) describes as the "social brain". Collaborative learning can be defined as a learning situation during which students actively contribute to the attainment of a mutual learning goal and try to share the effort to reach this goal. According to Cognitive Load Theory, learners in collaborative groups are considered as a single information-processing system, as the processing is divided across individuals (Eilks *et al*. 2009). Hands–on practical tasks afford students with the opportunity to interact with each other as well as the procedures and materials of science. Transforming group work into collaborative learning requires the class materials to be modified so that every member of the group is responsible for contributing to the group work and the group's success.

Lab Roles

To support the development of collaboration in our lessons, students are organised into groups of three which are maintained for all practical activities. The groups, like seating plans, are decided by the teacher and are maintained throughout the year so the class becomes accustomed to this style of working. Prior experience of collaborating as a team has been shown to increase efficiency and performance. Grouping students as trios rather than pairs reduces issues caused by a group member being absent, whilst still being a small enough grouping for everyone to be engaged. The roles in Figure 1 below, delineate the contributions each member is expected to make (Gaunt & Stott, 2018). The three lab roles are rotated within a group every practical lesson, so that every student experiences each role a number of times.

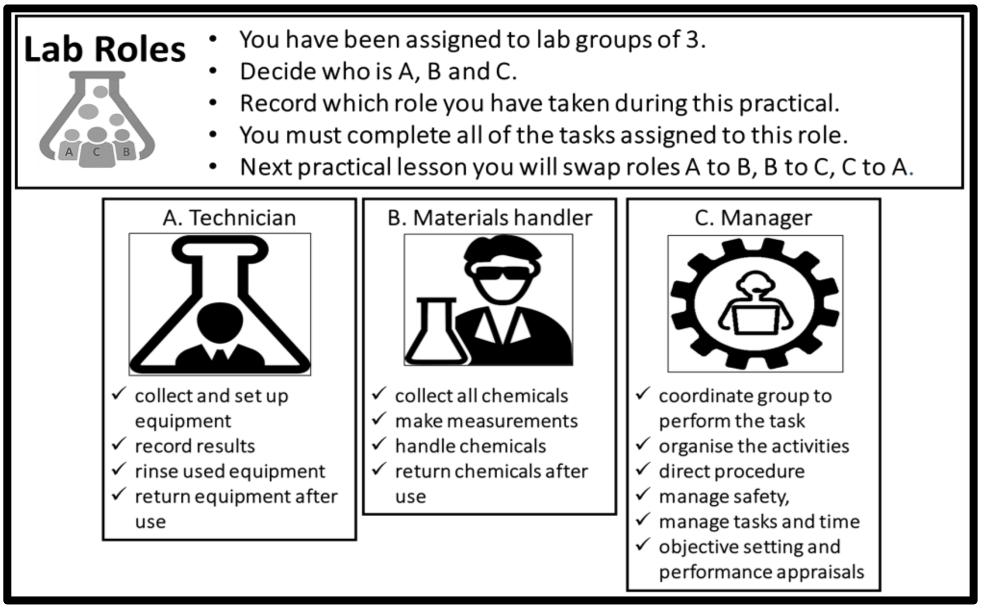

Figure 1: Lab Roles derived from the work of Ott *et al.* (2018) (Hennah, Newton and Seery, 2022)

Lab Talk

Evidence-based arguments form the basis by which scientific knowledge is used, tested and revised. The importance of argumentation in chemistry education, including in laboratory learning, is well documented (see Erduran, 2019). However, students need structures to support the development of their discussion and argumentation skills (Gaunt & Stott, 2018). We have introduced Lab Talk (Figure 2) alongside Lab Roles to provide this support and encourage discussion during practical work. We seek to provide students with time and opportunity to construct arguments such as: *evaluating data in terms of accuracy, and precision; identifying potential sources of random and systematic error; presenting reasoned explanations relating data to hypotheses; and drawing conclusions. Our goal is to develop discussion, so it is integral to the practical task and in this way create a hands-on and minds-on environment.*

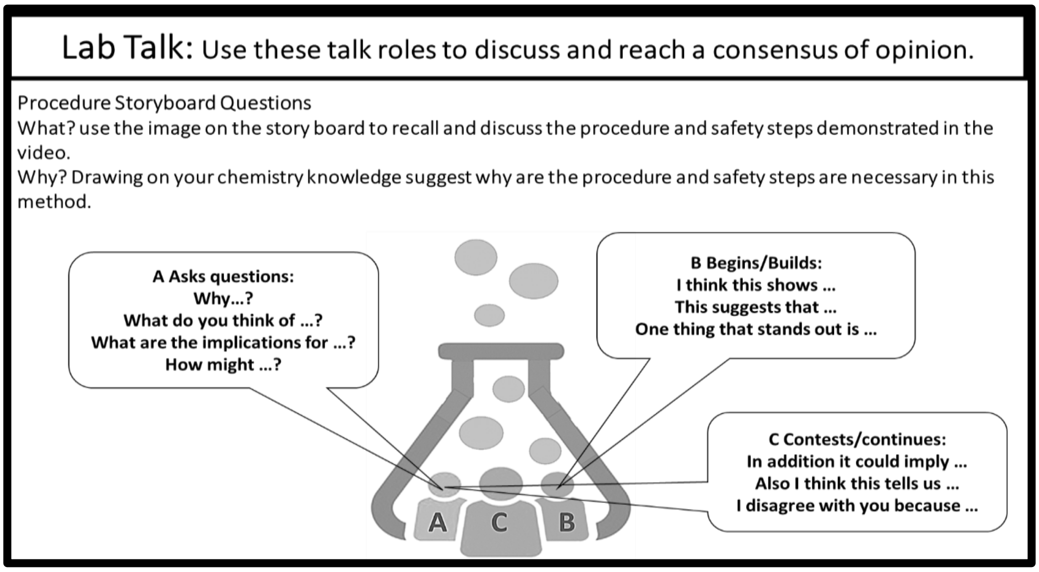

Figure 2: Lab Talk derived from the work of Gaunt, & Stott (2018) (Hennah, Newton and Seery, 2022)

A practical skills curriculum?

The adaptations suggested here support the classroom practitioner in improving the conditions for learning during practical tasks. Pre-laboratory preparation homework activities extend the time spent on practical work without taking up more teaching time. When students have prior knowledge of the task, the cognitive load imposed on the working memory by verbal and written instructions containing unfamiliar vocabulary, equipment and techniques is reduced, leaving more space for thinking. Training students to carryout hands-on tasks using Lab Talk and Lab Roles will facilitate collaborative learning once the approaches are established.

Encouraging students to talk and reason during the task builds familiarity with scientific language and culture but only if students are competent in science manipulative skills (Johnstone & Al-Shuaili, 2001). It is likely that the combination of a curriculum designed to develop scientific language, process competencies, and manipulative skills throughout compulsory education (see for example Hennah, 2018), as well as developing classroom practice as discussed here, would greatly improve school practical work.

Acknowledgements

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Biography

Naomi Hennah has been teaching school chemistry/science for nearly twenty years. Her classroom research is focused on oracy as a tool to build both familiarity and understanding of the language of chemistry. Since joining Northampton School for Boys in 2014, Naomi has completed a Master's degree in Education (Applied Linguistics) and was the Royal Society of Chemistry Schools Education Award winner for 2018.

ESTA Project: Teaching Science in Multilingual Classrooms

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Introduction

In this paper, we introduce the aims of the Erasmus+-funded project - Educating Science Teachers for All (ESTA) - in developing pedagogical approaches for teaching science in multilingual and multicultural classrooms. The ESTA project aims to address the challenges inherent in teaching science in increasingly linguistic and culturally diverse science classrooms. This requires changes to pre-service science teacher education curricula, and the provision of tailored workshops and supports to in-service science teachers. The ESTA project is driven by the work of an inter-disciplinary and international consortium of science teacher educators and linguists working together to build a transnational network of science teacher educators in order to develop and share evidenced based approaches to language- and culture- sensitive science teaching. The programme leads based at the SSPC Bernal Institute at the University of Limerick and in Ludwig Maxmilian University, Munich. are working in tandem with partner universities in Georgia, Bosnia-Herzegovina and the Philippines. For more information visit https://esta-project.eu.

Given Ireland's rapidly changing demographics, classrooms in Ireland are increasingly diverse and thus teachers need to adapt more inclusive pedagogical approaches to cater for this diversity. In teaching scientific subject knowledge and concepts, teachers must also consider the role of language and culture in their pedagogical approach. One of the remits of the ESTA project is to provide a number of frameworks and approaches to inform pre-service and in-service teacher training to guide development of inclusive language- and culture- sensitive science teaching in Ireland. Here we present theoretical perspectives on the role of language and classroom interaction in the learning process followed by practical approaches science teachers can take to begin embedding language and culture in their lesson planning and pedagogical practices to meet the needs of increasingly linguistically and culturally diverse learners.

Theoretical perspectives on the role of language and interaction in the learning process

In science classrooms, science teachers are not only engaged in developing the subject knowledge and skills of their learners, but they also function as language teachers, e.g. through the teaching of subject-related vocabulary. In fact, language plays a central role in the classroom since all learning is mediated through language in the negotiation of meaning and the construction of knowledge. Furthermore, it is also important for teachers to be aware of the importance of classroom interaction and language in achieving pedagogical goals and fostering learning. Linguistic analysis of classroom discourse and interaction has shown the interconnection between language, teacher-learner interaction and learning. The construct of Classroom Interactional Competence (CIC) was coined to describe 'teachers' and learners' ability to use language and interaction as a tool for mediating and assisting learning' (Walsh 2011 p.130). This research has shown that teachers with good levels of CIC can use classroom discourse and interaction to achieve a variety of pedagogical goals: supporting learning, managing the learning environment and actively engaging the learners. This can be achieved when teachers have the awareness to: use language effectively at different stages of the lesson; adjust language where necessary to facilitate the co-construction of meaning with their learners; allow learners the space and time to interact and make contributions and facilitate the use of extensive linguistic repertoires to achieve classroom pedagogic and learning goals.

Developing language awareness of teachers and learners

In addition to developing effective classroom interactional competence, how can teachers adapt their teaching in linguistically and culturally diverse classrooms and provide opportunities for students to be able to draw on their own language and linguistic repertoire for concept development and classroom activities? We propose that science teachers can use a variety of activities to develop their own language awareness and that of their learners as a first step towards using language and interaction to achieve their pedagogical goals. An important concept in this regard is that of linguistic repertoires, which we have mentioned above. An individual's linguistic repertoire is their set of abilities and expertise in one or more languages, as well as the various dialects within those languages. This repertoire includes all the linguistic varieties. This can be at the level of pronunciation, dialect, accent, text, visuals and non-verbal communication such as body language and gestures. Use of one's full linguistic repertoire can foster communicative competency. For example, in multilingual settings, learning can be improved when students collaborate and make use of their full linguistic repertoire in the classroom. The following are two examples of classroom exercises that can be used in multilingual classrooms at the start of the school year to familiarize students with their language repertoires and develop language awareness.

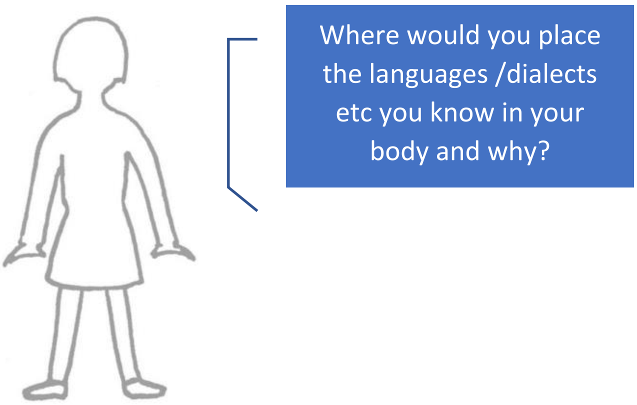

Figure 1: Language portrait

To develop teachers' and learners' awareness of what it means to be bilingual and multilingual, the use of language portraits as an ice-breaker activity at the beginning of the school year can help achieve this. A language portrait is an empty whole-body silhouette in which participants colour or draw languages they know and/or use. This exercise can form the basis of discussions between teachers and learners about the languages they know and use. When it is used in the classroom, the teacher can turn the language portraits of the learners into posters and hang them all over the classroom. Learners would thus have the chance to observe and read about a diversity of linguistic identities in their classrooms. This activity is beneficial for both teachers and learners because language portraits offer insightful information and material that can be used in class discussions to raise language awareness.

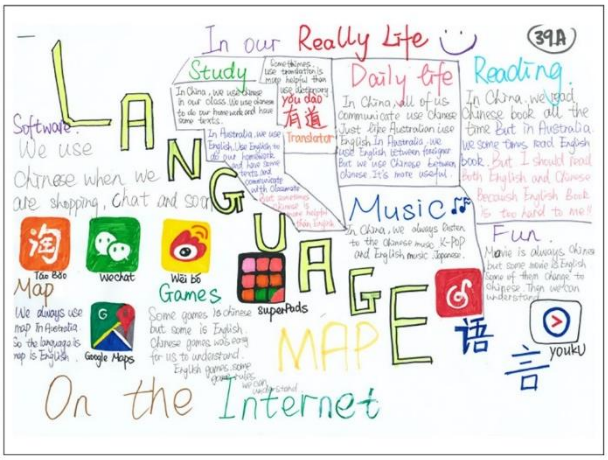

Figure 2: Language mapping (Slaughter & Cross, 2021)

To further develop awareness of the linguistic repertoire of their learners, teachers can also use a language mapping activity to stimulate learners' thinking about ***how, where, when, and why*** they use different languages for different purposes in their everyday lives (Slaughter & Cross, 2021). In this activity, learners create visual representations of their language practices both inside and outside school. The teacher provides guiding questions and visual materials to make this task familiar to the learners. This activity encourages learners to use any language they wish to create their own individual maps.

Language portraits and language mapping are useful tools for promoting language awareness in the classroom since they enable learners and teachers to reflect critically on their everyday linguistic activities and experiences.

Theory to practice: pedagogical approaches to use in the classroom

(1) Content and Language Integrated Learning CLIL):

CLIL, which combines content and language learning, (Surmont et al., 2014) is widely used in bilingual and multilingual classrooms, along with the teaching of second languages. When used in a science classroom, CLIL refers to integrating science subject content and skills with language learning. CLIL, as an approach, is flexible and adaptable. There is no single CLIL model and teachers can develop their own classroom practices based on the needs of their students. However, according to Coyle (2010), there are four fundamental principles which should underpin all CLIL models as proposed in the 4Cs framework of CLIL. This framework, as shown in Figure 3, takes account of the inter-relationship between content (subject matter), communication (language), cognition (learning and thinking) and culture (social awareness of self and others). For example, in planning science lessons in multilingual settings, this CLIL framework can guide teachers in how to integrate these four elements into their teaching approach as follows:

- **Content:** subject knowledge and skills that the teachers need to teach;
- **Cognition**: the teachers focus on the thinking skills that they want to develop;
- **Culture**: everything that the teacher teaches is based on learners' experiences. For example, if teachers teach healthy foods, learners can give examples from their local shops, their fridge or their villages/countries;
- **Communication**: the teachers encourage learners to work in teams & pairs and to speak using different communication tools.

These principles can also be seen as starting points in CLIL science lesson planning.

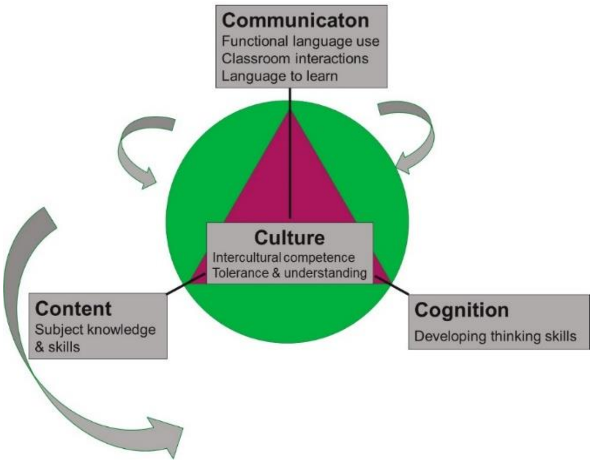

Figure 3: The 4Cs framework of CLIL. Adapted from Coyle (2010)

In this model, language is central in the acquisition of subject knowledge and skills by supporting learning and cognition. Consequently, learners need support in meeting the linguistic demands of both content and cognition in the learning process. In order to guide teachers in meeting the subject content, cognitive and linguistic needs of their learners, the 4Cs framework could be used at the lesson planning stage as shown in the sample lesson plan on habitats below (Table 1). Teachers can explicitly articulate the content and language aims to support learners in learning about this topic. This framework also encourages teachers to think about cultural aspects of the lesson topic to include all learners in concept development and relating the topic to their own experiences.

Table 1: Sample lesson plan to integrate content, language and culture into lesson planning

Theme/topic lesson	Habitats	
Lesson Aims: Content Aims	• To introduce the concept of habitat and its main features; • To help learners distinguish between different types of habitat; • To help learners recognise and classify living and non-living things; • To help learners identify how animals adapt to changes in habitat.	**Notes & examples**
Language Aims	• To introduce key topic-related vocabulary	e.g. habitat (n); living things (n) **[language of learning]**
	• To support learners' use of language to develop interaction and engage in classroom tasks	e.g. using questions, using language to classify, to compare & contrast; can anybody tell what this means? **[language for learning]**
	• To support learners' language development opportunities through extended activities	e.g. recycling lexis, learning new words from activities **[language through learning]**
Culture Aims	• To compare ecosystems in different parts of the world • To look at animals in different ecosystems	

The 4Cs framework of CLIL can also guide science teachers in embedding language in the teaching of content based on an approach supporting language learning through functional language use. For example, this can be achieved in supporting learners to learn the *language of learning* which is the content/subject-related language. Learners also need to be supported in developing the *language for learning* which is the language required to learn in the classroom and finally learners' language can be further developed *through learning* where learners are building on the language and knowledge they have learned through opportunities to actively engage in additional activities to construct and articulate new and existing knowledge. An example of how teachers might plan to embed a more language-using focus to their lesson planning is shown in Figure 4.

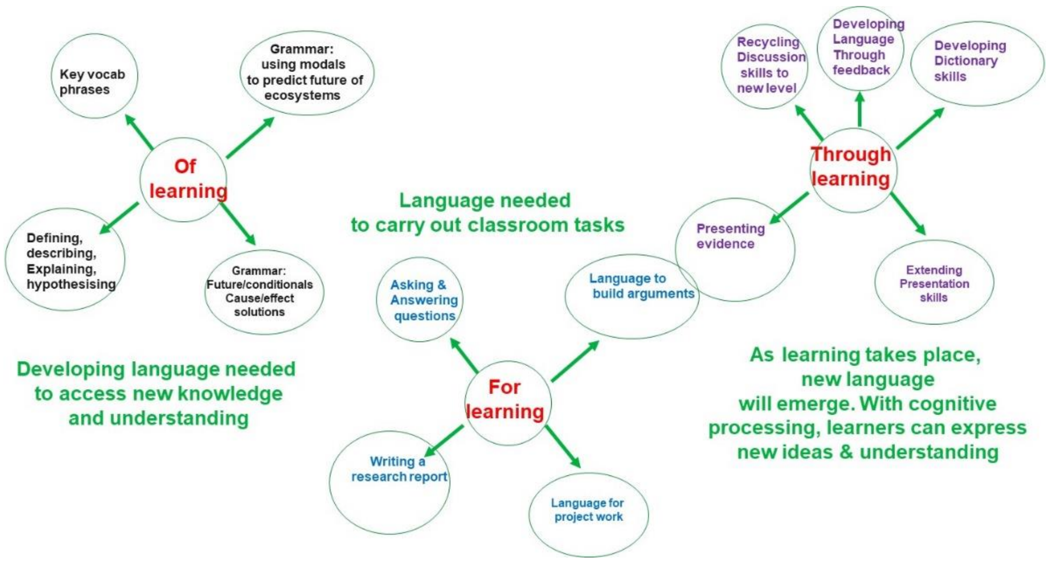

Figure 4: Developing a functional language using approach to support content & language learning in science classrooms (modifiedfrom Coyle et al. 2010)

It is important that science teachers develop their language awareness and are alert to the challenges posed in accessing scientific subject content. The language of science, which comprises terminology specific to that field, requires understanding of scientific phrases and words as well as the language required to function efficiently in the classroom when performing tasks like writing a scientific report or conducting experiments. The CLIL approach can support students in expanding their scientific vocabulary through using language to construct scientific knowledge. The following are common CLIL teaching strategies which can be applied in science classrooms: pre-teaching vocabulary; activating prior knowledge; using broad linguistic repertoire, e.g. visuals, gestures; pre-teaching vocabulary; giving students opportunities to use language; using show and tell methods e.g. step-by-step demonstration of steps in an experiment. The integration of CLIL approaches into Irish science classrooms will require a step- by-step approach and may require more collaboration between science teachers and language support teachers. However, CLIL frameworks such as Coyle's 4Cs model can provide a readily applicable framework that science teachers can use at lesson planning stage to help embed language and culture in the teaching of their subject knowledge and skills.

(2) Translanguaging

Translanguaging is another pedagogical approach to teaching in multilingual classrooms. Translanguaging is a relatively new approach and describes the process of switching between the languages one knows in order to maximise communication. According to Garcia *et al.* (2017), the concept refers to using the learner's entire language repertoire in teaching and learning. There are significant benefits for learners in using translanguaging approaches in the classroom such as development of own language, target language, content knowledge and social development. In the classroom, translanguaging practices can involve translating between languages; using key vocabulary, grammar and syntax structures in both languages (side to side) or using the home language in one part of an activity and the school language in another part.

The following are a range of translanguaging teaching techniques that science teachers can readily employ in their multilingual classrooms: learners take notes in their first language (L1); learners have opportunities to use their first language in pair- or group-work; the creation of bilingual and multilingual glossaries and the creation of translingual posters (as shown in Figure 5).

Figure 5: Translingual poster (Anderson, 2018)

Translingual posters are a very inclusive resource that can be easily used by science teachers in multilingual classrooms to provide learners with opportunities to prepare a poster on any topic in more than one language. Such posters can be made interactive by including cards that can be flipped where each card can have concepts described in more than one language. This promotes good levels of engagement from learners and can be a good way to teach scientific terms. The following is another example of a translanguaging activity that a science teacher used in a multilingual science classroom to teach vocabulary describing discrete steps in the scientific method (Figure 6).

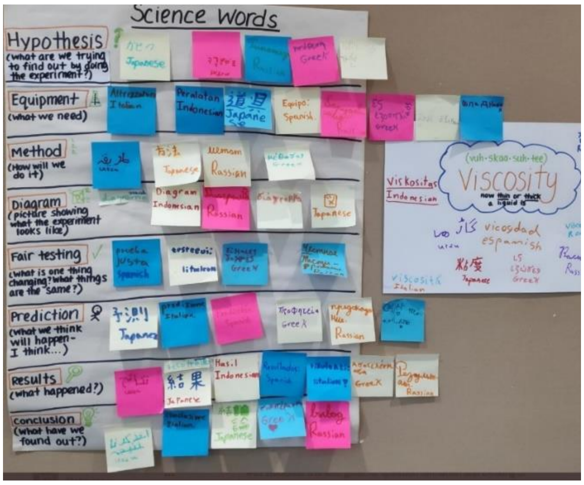

Figure 6: Translingual vocabulary activity (English as an Additional Language Department at the International School of The Hague, 2020)

This translingual vocabulary activity allows learners to write what each science term in English means in their native languages. This activity is useful as it represents all learners in the classroom and can help learners develop better understanding of science terms by finding their equivalence in their first languages. They can also explore the similarities and differences across the languages.

Conclusion:

Learning is a social process and is mediated through language. Science teachers, in addition to developing the subject knowledge of their learners, also guide their learners to develop the language necessary to construct knowledge, develop cognition, engage in classroom activities, interact with their peers and to construct and articulate knowledge. Understanding the primary role of language in the science classroom and having awareness of the full linguistic repertoire of their learners will be important as teachers teach in increasingly diverse science classrooms. We recognise the challenges teachers face in delivering busy science curricula, but we hope that some of the perspectives and approaches being promoted by the ESTA project will provide a good starting point for busy science teachers to take practical first steps to embedding language more explicitly into their lesson planning and pedagogical practices. The activities and teaching approaches described in this paper will encourage learners to use their full linguistic repertoires in the classroom while also allowing teachers to develop intercultural and inclusive science lessons that support students' first languages and target language. This will also enhance the teaching of scientific knowledge and skills in linguistic and culturally diverse classrooms.

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Biographies

Dr Ebru Eren is a postdoctoral researcher at SSPC, the Science Foundation Ireland Research Centre for Pharmaceuticals, at the University of Limerick, working on linguistic and cultural diversity in science classrooms. She graduated from Trinity College Dublin with a PhD in Education in 2021. She has a MA in Women's Studies and a BA in Teaching English as a Second Language. Before pursuing her PhD, she worked as a post-primary language teacher in Turkey between 2007 and 2017.

Dr Catherine Martin is a Lecturer below the bar in TESOL and Applied Linguistics in the School of Modern Languages and Applied Linguistics at the University of Limerick. She teaches language pedagogy at undergraduate and postgraduate level; English for Academic Purposes to international postgraduate students and English as a Medium of Instruction (EMI) to international academics. Her research interests include teaching in multilingual and multicultural settings, language for work and developing frameworks for curriculum development in the areas of EMI and professional English language. She currently supervises a number of PhD students in the areas of EAP, ESP and corpus linguistics.

Menacing Moles

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Although this article is entitled "Menacing Moles", it begins with a short summary of how the brain learns something.

So, how do we "learn" something?

To understand what learning is, we need to understand how the brain works. Human brains have two memory compartments: the long-term memory for storing information and the working memory for thinking.

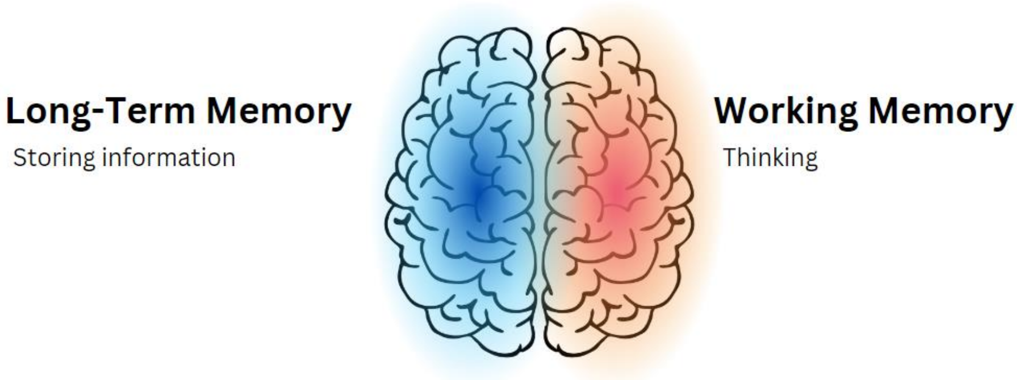

Figure 1: the two memory compartments of the brain.

In his book *The Teacher Delusion 3: Power Up Your Pedagogy,* Robertson (2021) explains how any information stored in long-term memory is considered as knowledge and when new information is presented to the brain, like a new topic for example, any prior knowledge of the topic (known as schemata), is retrieved by the working memory to make sense of it, through thinking.

Therefore, knowledge is what we think with in our working memory and store in our long-term memory. Having prior knowledge gives us more to think with, creates new memories to store and helps us learn new information easily.

Kirschner *et al.* (2010) also refers to this process in their article "Why Minimal Guidance During Instruction Does Not Work", when they defined learning as "creating a change in long-term memory".

Therefore, we can help our students learn better by making this change by transferring knowledge from their working memory into their long-term memory. We can do this by simply getting them to think more.

More evidence of this is seen in "Why don't students like school?" where the author, Willingham (2021), states, "people tend to learn what they think about". This is seen again when educational researchers, Coe *et al.* (2019), reported in their "Great Teaching Toolkit" that "learning happens when people have to think hard".

As the research all points towards ***thinking*** as being essential for learning, it is logical to assume that we should gear our lesson plans towards ***thinking***. However, we need to also be aware of cognitive overload. If students do not have sufficient prior knowledge of a topic (moles for example) before we introduce new information (such as Avogadro's constant), they will be unable to process the new information correctly, as there are little or sometimes no schemata to "pull" from the long-term memory to think with, in the working memory. Students end up being confused and will not remember any of the new information.

If they can't think about it, they can't learn it.

So how can we determine prior knowledge?

One way is to use diagnostic tests. Diagnostic testing is an efficient way to benchmark a class's understanding at the beginning of a topic. Knowing what they already know or lack knowledge in, we can tailor our lessons to fill the gaps and identify any misconceptions. It is particularly useful after a transition between levels of study, such as Junior cycle to Senior cycle.

Used correctly, diagnostic tests will identify prior knowledge of all the necessary skills and knowledge required to understand and apply the concept of the mole, before other related content is introduced, such as:

- calculating Relative Molecular Mass,
- rearranging and substituting formula,
- using standard form,
- understanding the concept of SI units and collective nouns.

In her article in "Diagnostic Tests for Better Teaching", Haxton (2018) talks at length about the benefits of diagnostic testing, suggests the best types of questions to use and recommends Google Forms for an easy platform for creating and marking the test. The article also includes an example of a test she created on spectroscopy.

Get students thinking from the start!

Bruce Robertson appropriately renames the traditional "lesson starter" as the "daily review", "weekly review" or "monthly review", depending on the content of the review. Bruce recommends doing all three types regularly as recalling knowledge from the long-term memory to the working memory after short time delays (after a day, a week and a month for example) has been shown to build schemata and improve memory.

Too many teachers do not take advantage of the beginning of a lesson as a learning opportunity, and instead, simply fill the void, with an activity that albeit, might be linked to the last lesson, but does not require the students to think much.

It makes much more sense that the daily review should include a task that:

- requires students to think with prior knowledge,
- uses questions to identify gaps in knowledge,
- provides motivation for students to study,
- includes questions that will show misconceptions and,
- with the results, allows teachers to pitch new content at the correct level of difficulty.

An example of a "good" daily review is a quick "5-a-day" pop quiz. It consists of only five questions but includes questions that requires a little more thinking.

For example (Figure 2):

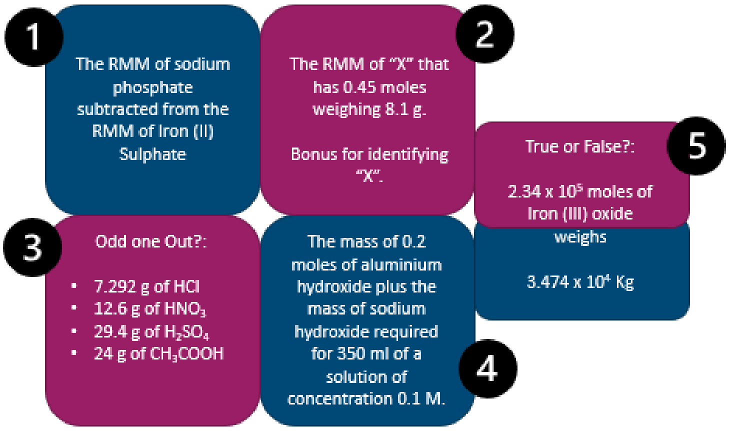

Figure 2: A 5-1-day pop quiz on moles.

Another great daily review activity is a Tarsia puzzle. Here is an example of one I created, on moles.

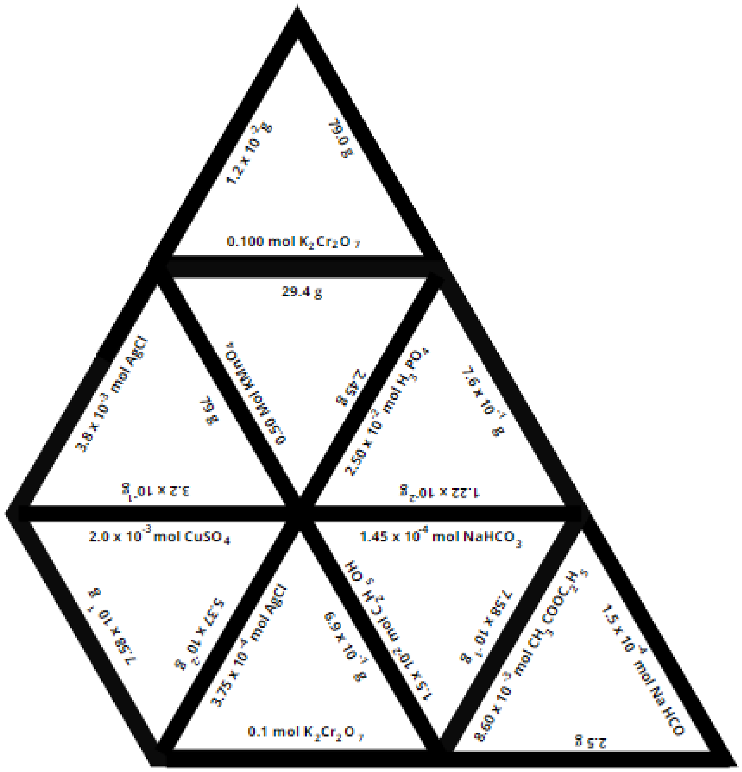

Figure 3: A tarsia puzzle on moles

A little more preparation is required for this one. One photocopied puzzle is required per student or pair of students and needs to be cut up and paper-clipped together before class. It works best if laminated.

The aim of the puzzle is to match the right answer to the question to re-form the original, correct shape. This one comes with a warning, however it can get very competitive.

These are two great examples, but my favourite are these worksheets from the RSC's "Starters for 10" Collection.

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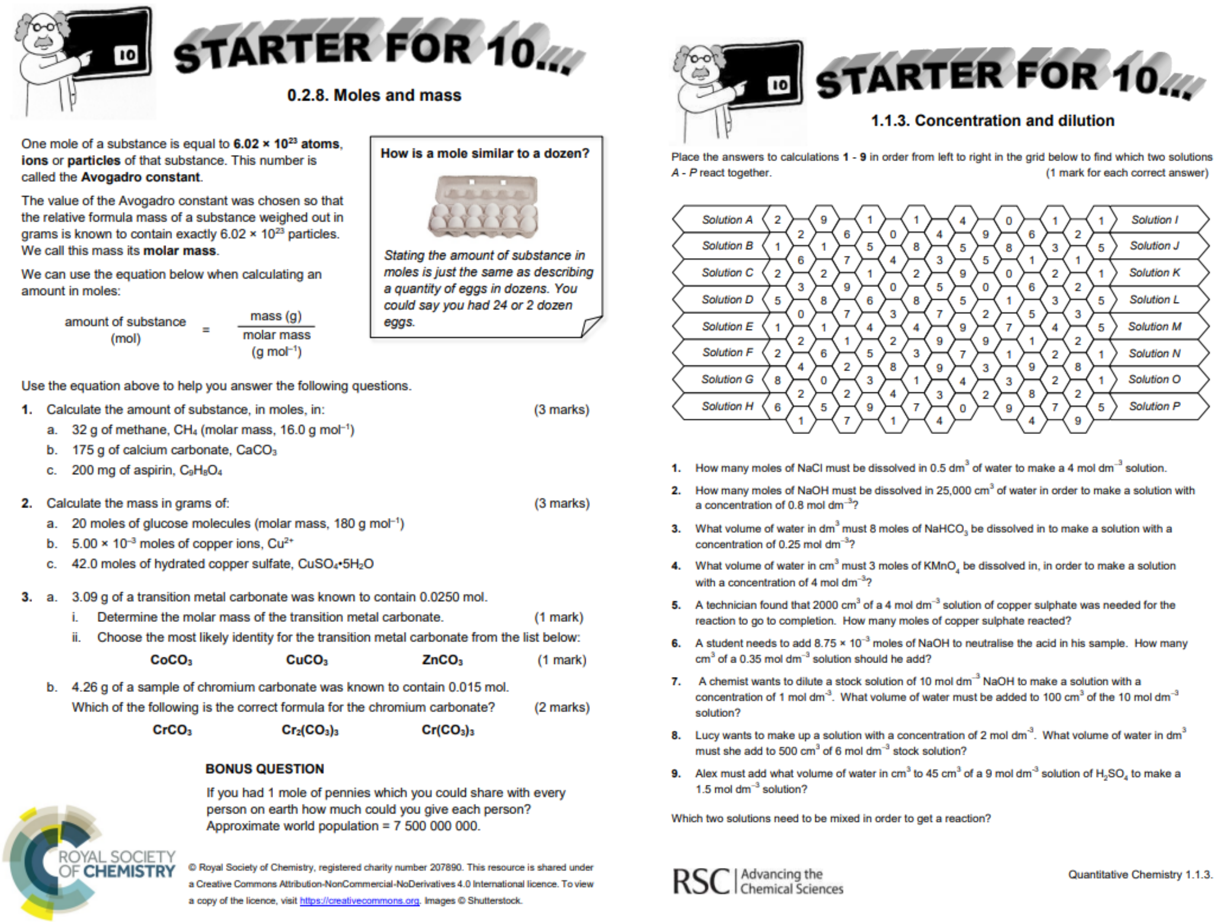
They are a collection of short quizzes designed to be used at the start of chemistry lessons. The basic mathematics starter quiz covers extensive maths topics, and their format is different to "typical" questions they might be used to, so thinking is required, and they are good fun.

Another great thing about this collection is that all the worksheets are downloadable in a pdf and word format (allowing you to edit them according to your awarding body, class ability etc.) but most importantly, they also come with the answers.



STARTER FOR 10...

0.2.8. Moles and mass

One mole of a substance is equal to **6.02×10^{23} atoms**, **ions** or **particles** of that substance. This number is called the **Avogadro constant**.

The value of the Avogadro constant was chosen so that the relative formula mass of a substance weighed out in grams is known to contain exactly 6.02×10^{23} particles. We call this mass its **molar mass**.

We can use the equation below when calculating an amount in moles:

$$\text{amount of substance (mol)} = \frac{\text{mass (g)}}{\text{molar mass (g mol}^{-1}\text{)}}$$

How is a mole similar to a dozen?

Stating the amount of substance in moles is just the same as describing a quantity of eggs in dozens. You could say you had 24 or 2 dozen eggs.

Use the equation above to help you answer the following questions.

1. Calculate the amount of substance, in moles, in: (3 marks)
   a. 32 g of methane, CH_4 (molar mass, 16.0 g mol^{-1})
   b. 175 g of calcium carbonate, $CaCO_3$
   c. 200 mg of aspirin, $C_9H_8O_4$

2. Calculate the mass in grams of: (3 marks)
   a. 20 moles of glucose molecules (molar mass, 180 g mol^{-1})
   b. 5.00×10^{-3} moles of copper ions, Cu^{2+}
   c. 42.0 moles of hydrated copper sulfate, $CuSO_4{\cdot}5H_2O$

3. a. 3.09 g of a transition metal carbonate was known to contain 0.0250 mol.
   i. Determine the molar mass of the transition metal carbonate. (1 mark)
   ii. Choose the most likely identity for the transition metal carbonate from the list below:
   $CoCO_3$ **$CuCO_3$** **$ZnCO_3$** (1 mark)

   b. 4.26 g of a sample of chromium carbonate was known to contain 0.015 mol. Which of the following is the correct formula for the chromium carbonate? (2 marks)
   $CrCO_3$ **$Cr_2(CO_3)_3$** **$Cr(CO_3)_3$**

BONUS QUESTION

If you had 1 mole of pennies which you could share with every person on earth how much could you give each person? Approximate world population = 7 500 000 000.

ROYAL SOCIETY OF CHEMISTRY

STARTER FOR 10...

1.1.3. Concentration and dilution

Place the answers to calculations **1 - 9** in order from left to right in the grid below to find which two solutions *A - P* react together. (1 mark for each correct answer)

1. How many moles of NaCl must be dissolved in 0.5 dm^3 of water to make a 4 mol dm^{-3} solution.
2. How many moles of NaOH must be dissolved in 25,000 cm^3 of water in order to make a solution with a concentration of 0.8 mol dm^{-3}?
3. What volume of water in dm^3 must 8 moles of $NaHCO_3$ be dissolved in to make a solution with a concentration of 0.25 mol dm^{-3}?
4. What volume of water in cm^3 must 3 moles of $KMnO_4$ be dissolved in, in order to make a solution with a concentration of 4 mol dm^{-3}?
5. A technician found that 2000 cm^3 of a 4 mol dm^{-3} solution of copper sulphate was needed for the reaction to go to completion. How many moles of copper sulphate reacted?
6. A student needs to add 8.75×10^{-3} moles of NaOH to neutralise the acid in his sample. How many cm^3 of a 0.35 mol dm^{-3} solution should he add?
7. A chemist wants to dilute a stock solution of 10 mol dm^{-3} NaOH to make a solution with a concentration of 1 mol dm^{-3}. What volume of water must be added to 100 cm^3 of the 10 mol dm^{-3} solution?
8. Lucy wants to make up a solution with a concentration of 2 mol dm^{-3}. What volume of water in dm^3 must she add to 500 cm^3 of 6 mol dm^{-3} stock solution?
9. Alex must add what volume of water in cm^3 to 45 cm^3 of a 9 mol dm^{-3} solution of H_2SO_4 to make a 1.5 mol dm^{-3} solution?

Which two solutions need to be mixed in order to get a reaction?

RSC | Advancing the Chemical Sciences

Quantitative Chemistry 1.1.3.

Figure 4: Two "Starters for Ten" activities on moles.

Why do students find the topic of moles, so difficult?

Warren (2015) summarises the findings of research into this question in her article "Moles and titrations: scary stuff?"

The main reasons why students struggle with moles are because:

- Chemists do not agree on how the mole should be defined;
  - as an individual unit of mass,
  - as a portion of substance or,
  - a number.
- The mole is taught as an abstract mathematical idea.
- Students lack secure understanding of preliminary concepts including:
  - Chemical reactions produce new substances (perhaps because of not enough practical, where they can observe reactions actually happening and new substances being formed. Read what, Nikki Kaiser (2020) has to say on the importance of practical in her article "Practical ideas for using Johnstone's triangle".
  - Matter is made from tiny particles invisible to the naked eye (perhaps show a video of the smoke particle experiment, such as the one by Frank Scullion (2013**)** to demonstrate the existence of air particles).
  - Chemists need to be able to measure amounts of substances accurately to be able to control a reaction.
  - Avogadro's number cannot be 'seen' (perhaps more time needs to be spent on standard form and collective nouns).

To get our students thinking about content we would like them to learn, we need to grab their attention to it. However, we want to do this in such a way that is effective and not distracting. Therefore, we need to be careful about what we are creating attention to and try and control their thought process through careful manipulation.

One obvious example of this is with the use of images and GIFs in presentation slides. Use images, of course, but be strategic. Sometimes adding an image just for the sake of it, to make the slide look "better" or to fill a gap, isn't always a good idea. The class will be too busy looking the image, trying to see the relevance, or thinking on something else that was triggered by the image rather than what you want them to think on.

One thing you could do to grab their attention is by using "hooks", such as putting key words in bold/italics or in a different font, or appropriate images, such as this Moles infographic poster below, from an Education in Chemistry article (Sieber 2022) on Moles and Avogadro's constant.

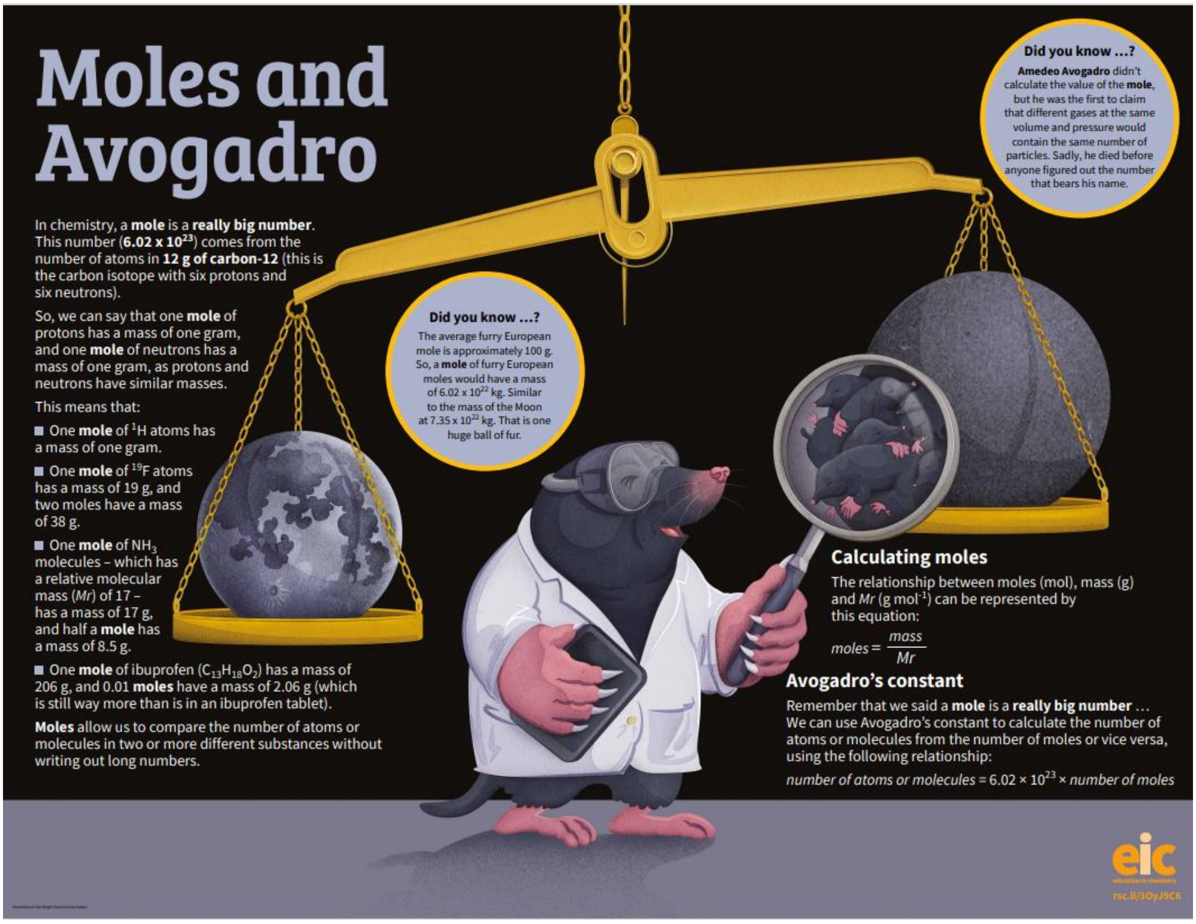


Figure 5: Moles and Avogadro poster from *Education in Chemistry*.

To maximise thinking potential, and therefore learning, we want to make sure we keep cognitive load to a minimum.

What is Cognitive Load?

Any task that exceeds the limit of the working memory will result in cognitive overload and this increases the possibility that the content may be misunderstood and not effectively stored in the long-term memory.

So how does this happen?

1. If teacher instruction and explanation are not clear (not enough modelling).
2. The subject knowledge is challenging and not yet secure (not enough formative assessment, which might show it is necessary to re-teach the content, using a different activity).
3. Questions do not reflect the examples in the teacher explanation or are too

difficult (not enough modelling and scaffolding).

4. There is a perceived pressure to move from teacher-led to student-based learning before the students are ready (**Shibli 2022**).

Scaffolding (building on existing experience and knowledge) and ***modelling*** (demonstrating a new concept and the students learn through observation) are very effective strategies to prevent cognitive overload.

One fantastic scaffolding activity is to u**se** recipes as a fun, accessible introduction to why and how we use balanced equations. Short (2012) explains in his article "Baking with Moles", how it can help students become more comfortable with ratios, excess and limiting reagents and gram formula mass using a cooking equations worksheet and answers.

And in her article "Mastering Moles", Sieber (2019) recommends simply rethinking the way we teach moles and describes five ways we can scaffold the concepts much better for all students.

As a result:

- higher attainers will develop deeper understanding, and
- lower attainers will tackle mole questions with confidence.

Sometimes moles calculations require a little more attention and scaffolding and modelling them in live time or on video can be very beneficial for learning. By providing a carefully constructed instructional "map" of how to do a particular calculation, cognitive load can be kept to a minimum, leaving more working memory space free, for thinking.

By demonstrating a worked example in live time (using a visualizer for example), teachers can break the process down into several smaller steps, and ensure the content is processed gradually rather than all at once. This way, long term memory can store each chunk of information separately and give working memory access to it when required for them to think about what they were shown.

Recording videos of modelling calculations is even better than that because students can pause and rewind and pause and rewind again, until they can independently complete the calculation without the support of the video.

Two other modelling techniques include:

- "I do, we do, you do", where the teacher demonstrates a worked example, then students complete a question in pairs and lastly, they do one independently, and
- "split screen", which involves always having the teacher's worked example on show/available on a worksheet for the students to use as reference while the complete their own.

For more information on modelling, check out Rule number 3 from the *Education in Chemistry* article on the seven simple rules for science teaching, which support the effective, evidence-based principles of the Education Endowment Foundation (2022) 'Improving secondary science guidance.'

Practice, practice, practice

We know it is important to provide students with repeated opportunities to practice solving questions and in this paper from the *Chemistry Education Research and Practice* journal, (the journal for teachers, researchers and other practitioners in chemistry education), researchers examine how the presentation and format of practice questions influences students' problem-solving performance.

The study carried out by the University of California-Davis, (Gulacar *et al*. 2022) revealed that mixed problem sets are better than questions arranged by topic.

Based on their findings, they concluded that teachers should:

- source or compile more mixed practice question banks, and avoid solely using topic-specific question sets from textbooks,

- increase the difficulty and benefits and not to include details identifying the relevant topics or chapters,

- still use block practice for certain topics: calculations with several steps may still require extensive blocked practice before engaging with the benefits of interleaved practice.

Other ideas include:

- separating the steps of a calculation and asking the students to put them into the correct order,
- providing them with a solution to a question with an intentional error to locate and amend is another great activity for making them think whilst practicing!

Exam Preparation

The Royal Society of Chemistry have an impressive collection of resources on revision (that can be easily applied for the topic of moles).

In his article "The Smart Way to Study", Busch (2022) looks at the following three revision decisions your students need to make, and how to help them succeed in their science exams:

- re-reading v. retrieval,
- listening to music v. silence while studying,
- procrastinating v. planning.

Lastly, in her *Education in Chemistry* article, Turner (2018) explains how to use past paper exam questions to develop ten deeper cognitive skills in:

- vocabulary development,
- unit conversion,
- equation practice,
- drawing structures,
- bond revision,
- structuring long answers,
- revising state symbols,
- scaffolding math calculations,
- making concepts stick,
- discounting the distractors.

How about calculating the number of grams in every concentration mentioned in the paper for example?

If anyone would like an email a digital version of this article for quick links to all the resources mentioned, please don't hesitate to get in touch. These are available in the electronic version of CinA!

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□

Biography

Dr. Johanne Brolly is an Education Coordinator for the Royal Society of Chemistry with 17 years' experience working in the Further Education sector in Northern Ireland as a chemistry teacher. She also has experience as a Teaching and Learning Advisor, supporting colleagues in their classroom practice and producing and coordinating their Professional Development.

Reflections on LC Chemistry

Fiona Desmond

Chief Examiner, LC Chemistry, Schools Examinations Commission

Fiona.Desmond@examinations.ie

Introduction

The lecture began with a brief review of the arrangements for LC Chemistry examinations in 2020, 2021 and 2022 put in place in response to the Covid-19 impact on teaching and learning. Known arrangements for LC Chemistry 2023 were previewed: June exams are not optional in 2023, an adjusted paper layout as in 2021 and 2022 will be used, but there will be less choice (i.e. candidates must answer 8 questions and not 6). The Chief Examiner's lectures at ChemEd-Ireland usually report on results and performance of candidates but given the circumstances of recent examinations, the opportunity was welcomed to focus on a few other issues for a change. Thanks to Marie Walsh for the invitation to speak at ChemEd-Ireland 2022 at TUS.

Choice in examination papers

Some of the advantages of choice in examination papers were mentioned: psychologically comforting, liberty, autonomy, reduces workload while preparing, can compensate for situation where the full syllabus cannot be covered, allows candidates to showcase attainment in their selection of syllabus objectives if this is acceptable. Some of the disadvantages of choice in examination papers were also mentioned: candidates don't always make wise choices, candidates sit different exams – reliability reduced, onus on setter to make questions of comparable difficulty, course cutting (by teacher and candidate) **with loss of syllabus coherence**, difficult to assess attainment of full range of syllabus objectives – validity reduced.

In particular with reference to LC Chemistry assessment, there is general agreement that the terminal examinations influence what happens in the classroom, that good examinations have a positive influence, that the current syllabus was designed to be taught and learned in its entirety and its coherence would be compromised in the long term by too much choice in exam papers but that limited choice is not damaging.

To help candidates of 2023 cope with a move to restore the intended syllabus choice the Chief Examiner recommends, on the basis of feedback from examiners in 2022 and her own observations:

- that candidates practice past questions and get feedback from their teachers on their attempts to answer practice questions,
- that candidates should have an awareness of value of practicing set pieces, e.g. graph drawing, stating definitions, performing calculations of certain types,
- and that candidates should understand the consequences of omitting/neglecting key topics like organic chemistry, chemistry of the periodic table, practical work, etc.

All candidates, and in particular Ordinary Level candidates, should be aware that in 2023 the time per question is 22.5 minutes, that each question is worth 50 marks and that every 6 marks worth is 1.5%.

Teaching and learning Chemistry

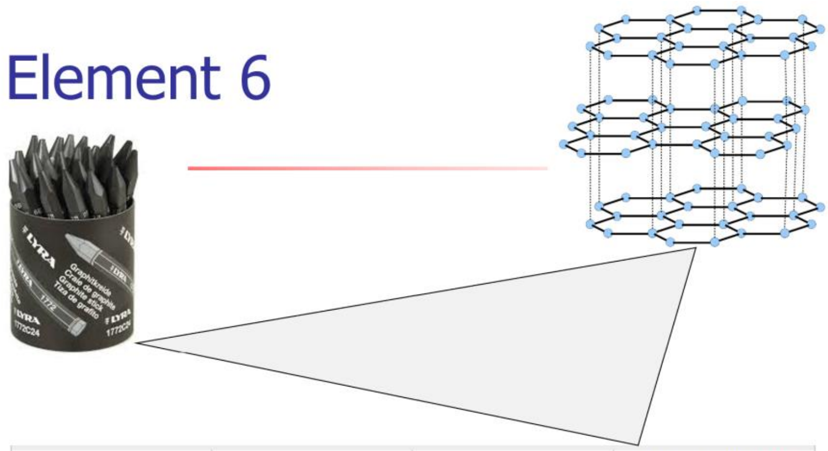
Chemistry, like all academic disciplines, is a network of concepts, but probably unique to Chemistry, learners must acquire additional layers of understanding at the macroscopic, microscopic and symbolic levels.

Alex H. Johnstone noted in the early 1980s, in a short paper about the nature of a chemistry curriculum suitable for all learners, that chemists *'view our subject on at least three levels'* and '*jump freely from level to level in a series of mental gymnastics'*. Later Johnstone represented the levels as a triangle with the following as vertices:
Macroscopic – observable, measurable, experiments and experiences, etc.
Sub-microscopic – abstract, based on indirect evidence, atoms, molecules, electrons, bonds, etc.
Symbolic – representational, models, formulae, equations, numeric representation, etc.

Simplistically Johnston's triangle could be exemplified if we think of water the liquid as macroscopic, the formula H_2O as symbolic and a V-shaped Molymod model of a water molecule as microscopic. A more complicated example would be consideration of carbon in the figure below.

It might also be useful to reflect on which activities in Chemistry teaching and learning belong to which vertex of Johnston's triangle, bearing in mind that an activity could belong to more than one vertex, as shown below.

It is worth noting that students often want to remain in the macroscopic – 'Can we do an experiment today?', and school management often show great interest in the macroscopic for school open nights and are less impressed by the symbolic or the microscopic. The teacher must work hard to introduce and develop the symbolic and the microscopic understanding.

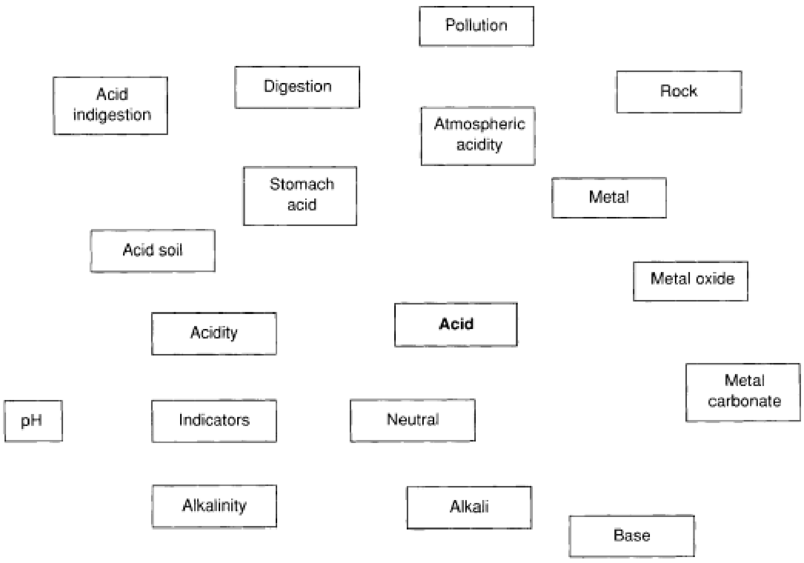


Group	14	Melting point	Sublimes at 3825°C, 6917°F, 4098 K
Period	2	Boiling point	Sublimes at 3825°C, 6917°F, 4098 K
Block	p	Density (g cm^{-3})	3.513 (diamond); 2.2 (graphite)
Atomic number	6	Relative atomic mass	12.011
State at 20°C	Solid	Key isotopes	^{12}C, ^{13}C, ^{14}C
Electron configuration	[He] $2s^22p^2$	CAS number	7440-44-0

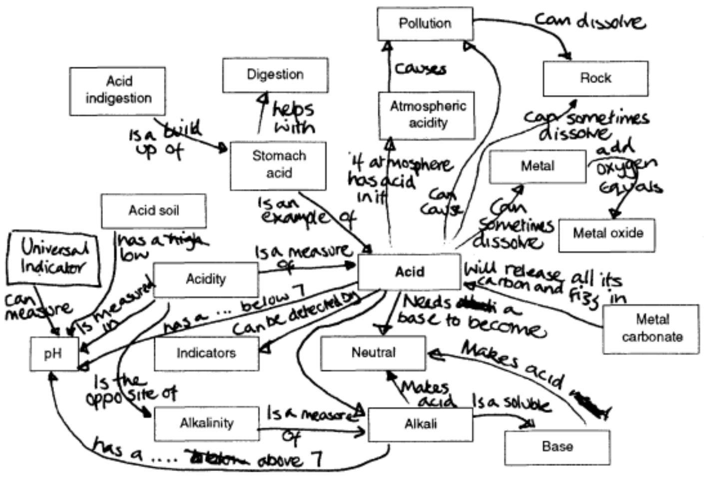
A few past LC Higher and Ordinary level examination questions were briefly reviewed in terms of how they explored macroscopic, microscopic and symbolic understanding and how candidates needed to be able to *'jump freely from level to level'* while answering the questions.

Concept mapping

Chapter 3 'The structure of Chemical Knowledge' in Keith Taber's (RSC) book Chemical Misconceptions deals with concept maps. A few extracts from this Chapter given below explain the idea of concept maps in Chemistry teaching and learning.

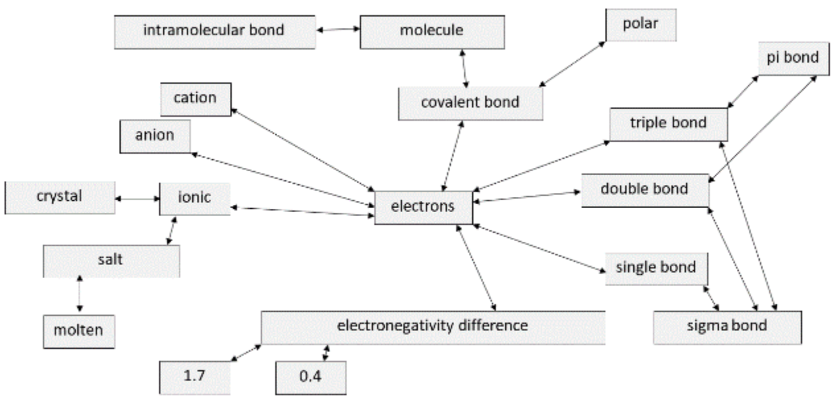


A partial concept map for acid



An example of a student's completed concept map

The Chief Examiner suggests that concept maps could be a useful tool in the classroom for teaching different levels, for revision, for encouraging active learning, as exercises for students to do if finished another task early, etc. Students could make their own or use a template provided by the teacher. They can be used across a range of topics. Concept maps are relatively quick to put together from scratch and students could be encouraged to add more boxes and add more connections to a template like the one below, about chemical bonding, in which the student task was to make connections between the boxes – one for each double-sided arrow.



A concept map for chemical bonding

Ordinary Level

It was suggested that Ordinary Level Chemistry candidates would benefit from focussed teaching and revision. They need some help with examination preparation highlighting the Odinary level paper specifically. They need encouragement and to understand that a little Chemistry knowledge goes a long way in the Ordinary Level Examination paper, i.e. similar questions frequently repeat from year to year and a bit of late revision would pay off. Lots of worksheets to encourage active learning and connecting of concepts, e.g. concept maps would be helpful as would working with past examination questions, practicing set pieces e.g. simple calculations, graph drawing, etc.

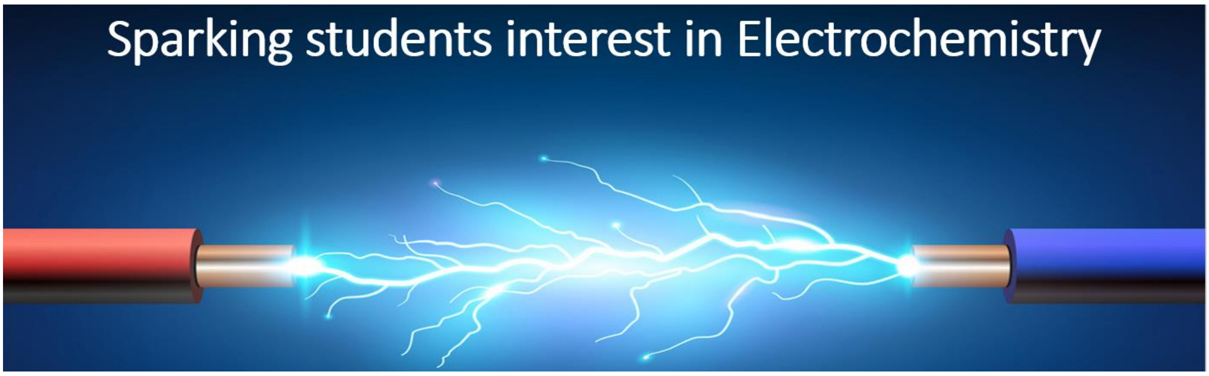
Inspiration

Finally, students and teachers of Chemistry may like the portrait of Ana Mayer Kansky which is used to illustrate Wikipedia's entry for Chemistry. It's an interesting and beautiful painting by Henrika Santel of an industrial chemist at work in 1932. In 2023 we hope she would have been painted wearing eye protection.

□

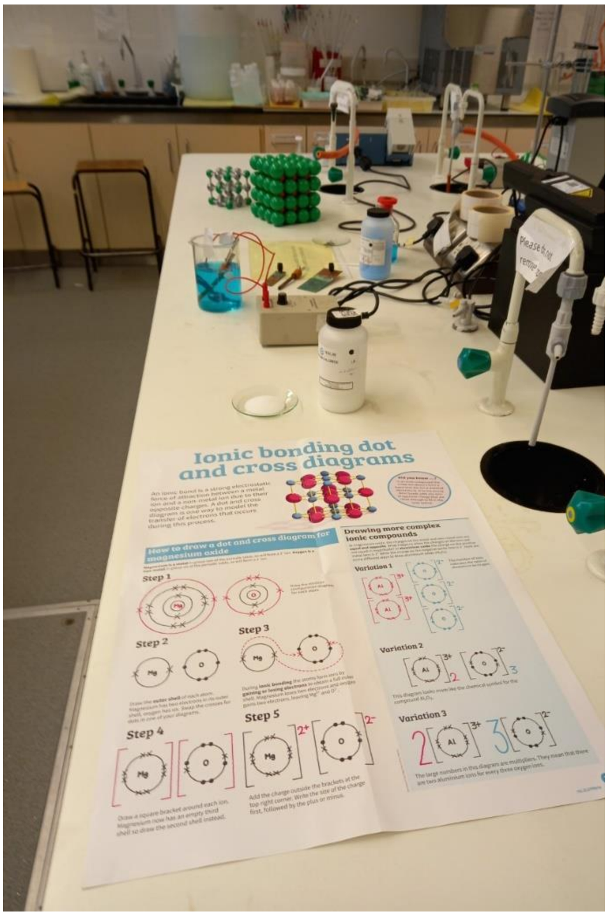
Biography

Fiona Desmond has been the Chief Examiner for LC Chemistry and for LC Physics and Chemistry for the State Examinations Commission since 2013. Her role is to set fair, quality state examinations and overseeing their marking. Prior to 2013 Fiona was a teacher of LC science subjects, Mathematics and Applied Mathematics and PLC subjects at the Cork College of Commerce which is part of Cork ETB.



David O'Connell
Head of Chemistry, CBC Cork.
david.oconnell@cbccork.ie

In this workshop, participants gained hands on experience in "conducting" some experiments related to the "field" of electrochemistry and electrolysis.



Participants had the opportunity to assemble a lemon battery in order to power a LED. A Galvanic cell was on also display to relate the concepts of the electrochemical series and electrochemical cells together (see below).

'Green hydrogen' generation was demonstrated by using a solar panel linked to a mini Hofmann voltameter in order to separate oxygen and hydrogen from water. This forms a link with teaching sustainability and renewable energy.

Particular focus was on the experiments relevant to the Higher Level Leaving Certificate Chemistry syllabus. This included the electrolysis of acidified water, a sodium sulfate solution and a potassium iodide solution. A demonstration of electroplating also featured along with some metal displacement reactions.

Activity: The Lemon Battery

Equipment and chemicals

Five lemons, copper plates (or old pennies/copper coins), zinc plates (or galvanised nails), sandpaper, wires with crocodile clips, small bulb or LED, multi-meter, small sharp knife.

Safety

Care should be taken when pushing the metal strips into the lemon as they can be sharp. Using a small knife to make a small hole in the lemon first will make it easier to insert the strips.

Procedure

1. Roll the lemons along the bench while gently press down on them, but without breaking the skin. This will release the juices inside the lemon and help the battery to function more effectively.
2. If using a copper coin and a galvanised nail as the electrodes, give them a rub with some sandpaper. This will remove any residue on the surface of the metals and help to expose the fresh metal underneath. Having pure copper and zinc plates are better as they will conduct more efficiently than the coins or nails.
3. Using a small knife, cut two slits on the top of the first lemon, about 1 cm apart.
4. Insert the copper electrode straight down into one slit and the zinc electrode into the other slit. Make sure that the electrodes are not touching inside the lemon. This is a single cell battery. The copper and zinc act as electrodes and the juice of the lemon acts as the electrolyte.
5. Connect the crocodile clips to the electrodes and ensure that they are as close to the surface of the lemon skin as possible. Insert the other ends of the leads into a voltmeter to the see if voltage is produced.
6. In order to power a small bulb or LED more cells need to be made and connected together in series to make a battery.
7. Repeat steps 1-4 above on four more lemons. This will make a five-cell battery.
8. Using the crocodile clips, connect the zinc electrode on the first lemon to the copper plate on the next lemon and so on.
9. Test the voltage again using the voltmeter.
10. Now connect the first and last crocodile clips to either side of the LED or bulb. If using a LED, ensure that the connections are correct - on a standard LED light bulb the longer pin is the positive connection and the shorter leg is the negative connection. It is also helpful to test the LED first before connecting it to ensure it is in working order.

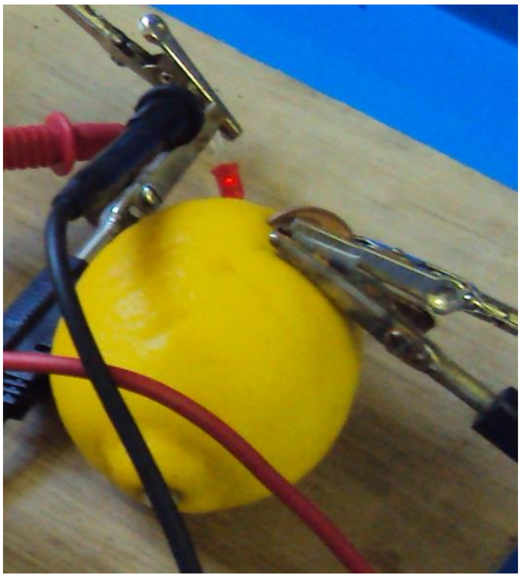


Figure 1: LED glowing red.

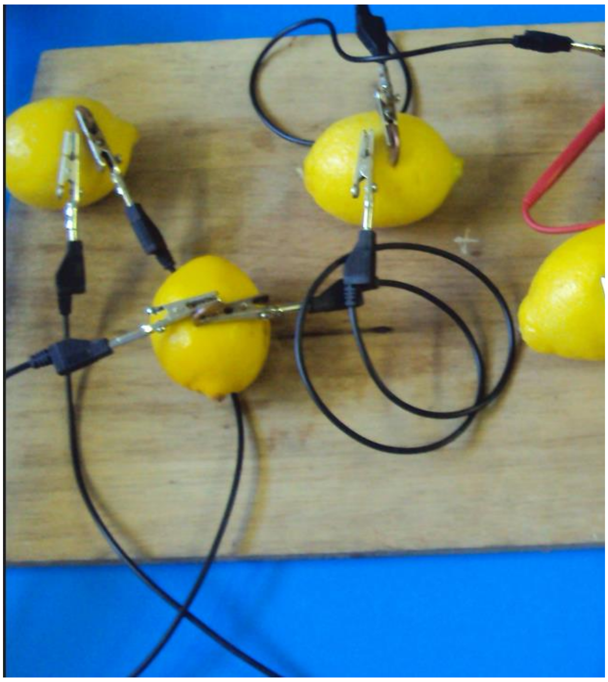


Figure 2: Apparatus used to create the lemon battery

Suggested results

The five lemons used in this experiment produced 1.71 volts and was enough to power a regular LED.

Discussion

The lemon cell battery is an example of an electrochemical cell and generates electrical energy from the oxidation-reduction reactions occurring within it. In the lemon cell battery, metallic zinc is oxidized at the anode and enters the acidic solution as Zn^{2+} ions:

$$Zn(s) \rightarrow Zn^{2+}(aq) + 2e^-$$

At the copper cathode, water from the electrolyte is reduced to form hydrogen gas:

$$2H_2O(l) + 2e^- \rightarrow 2OH^-(aq) + H_2(g)$$

The electrons used in forming the hydrogen are transferred from the zinc through the external wires connecting the copper and the zinc. The hydrogen molecules formed on the surface of the copper by the reduction reaction will ultimately bubble away as hydrogen gas.

Did You Know?

The Royal Society of Chemistry and Professor Saiful Islam have set a new **GUINNESS WORLD RECORDS™** title for the highest voltage from a fruit battery.

The team used 2923 lemons to generate an astonishing 2307.8 volts, which launched a battery-powered go-kart. The electrifying feat was designed to highlight the importance of energy storage and the need for new innovations for a zero-carbon world.

https://www.rsc.org/new-perspectives/sustainability/rsc-lemon-battery-breaks-guinness-world-records/

Video Resources – YouTube links

Lemon battery breaks Guinness World Record - Royal Institution Christmas Lectures 2016 - BBC Four
https://www.youtube.com/watch?v=6fDail5bvss

Breaking the GUINNESS WORLD RECORDS™ title for the highest voltage from a fruit battery
https://www.youtube.com/watch?v=DzLqJoczEpo

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Biography

David O'Connell graduated from UCC with a BSc(Ed) in Science Education in 2012 and has been teaching in CBC Cork for the past 10 years. He has delivered various CPD events for the ISTA and at ChemEd during that time. David was also involved in creating video content for the textbooks Chemistry Live! and Essential Science for Folens over the past number of years and is co-author of the Folens Bridge the Gap Transition Year Chemistry textbook.

Are Bioplastics a Solution to Single-Use Plastics?

Kevin Logan and Rob O'Leary
JCT Science Team

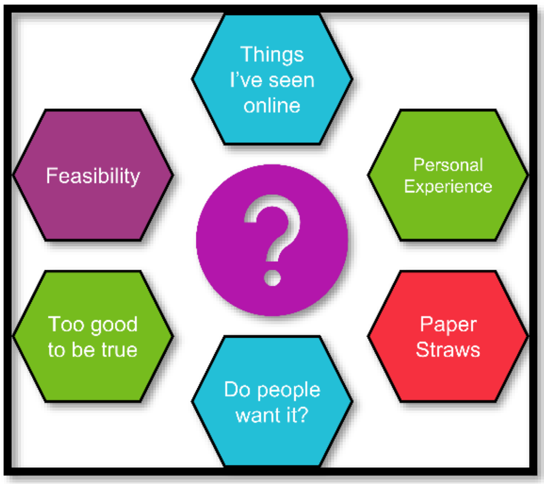
The JCT Science team facilitated a workshop at the ChemEd-Ireland 2022 conference. We looked at how it is possible to make a bioplastic from materials found at home and investigated whether bioplastics are a solution to single-use plastics.

We began the workshop with a video of a simulation of how many plastic bottles humans produce. Humans produce 20,000 plastic bottles a second and the video shows the scale of this production by simulating 20,000 bottles, per second, falling on a neighbourhood area. We then asked participants how the video made them feel. https://youtu.be/M1_zb10euFo

The Junior Cycle Science Chemical World learning outcome 10 states that: "*Students should be able to evaluate how humans contribute to sustainability through the extraction, use, disposal, and recycling of materials*". This learning became our focus of our workshop.

After the video, we clarified commercially used terms around bioplastics. We defined a bioplastic as a plastic material, which is either bio-based or biodegradable but can be both. We also defined bio-based as materials that are used which are grown from biomass, such as materials like; corn or sugarcane. The last definition we gave was for biodegradable and how it means the plastic material will break down by the action of microorganisms and turn itself back into biomass; water and CO_2.

We then projected a statement on the screen "Bioplastics are a suitable alternative to traditional plastics". Participants then discussed their own opinions and suggested what their



students would have to say in response to the statement. We shared some further suggestions.

After this, we took a moment for reflection. We had looked at the impact of plastics on the environment, discussed what a bioplastic is and its prospect of being a solution to traditional plastics. Our suggestion to participants at this point was that after such an experiment our students would now want to know more about bioplastics. We then went through an experiment showing participants how students can make their own bioplastic using potatoes as the bio-base.

Finally, after the participants made their bioplastics, we looked to see if there were ideas around testing the bioplastics they made to further explore if they could indeed replace traditional plastics. All of the resources may be found on the JCT Science website: Are Bioplastics a Solution to Single-Use Plastics?

□

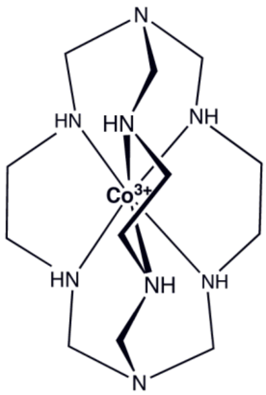
For information on the work of the JCT Science team see:
Science | Junior Cycle for Teachers (JCT)

Chemlingo: Chemicals to kill for

Peter E. Childs

We all know that molecules can kill, depending on their toxicity and dose. The word toxic comes from the Greek *toxikon*, meaning used on arrows (*toxon*), as often arrows were tipped with poison. From this we get toxicology, the study of poisons. The key thing about a poison is that it can cause death, depending on the dose. A poison is lethal, causing death, from the Latin *lethalis* = death.

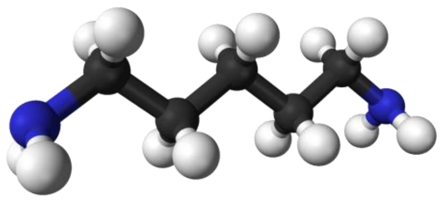
The prefixes *necro*- and *thanato*- are to do with death. Necro- comes from the \Greek *nekros* = corpse. Thus a necropolis is a place of death, a cemetery, where dead bodies are interred. Cemetery comes from the Greek for a place to sleep, a nice description of one's last resting place. The mortuary (Latin *mortuus* = dead) is where bodies are kept prior to burial or cremation. In Roman times bodies were often placed in a limestone *sarcophagus*. This word means body-eater as they believed that the limestone helped the decomposition of the body. Bodies were also placed in sepulchres, from the Latin *sepulcrum* = burial place. An interesting modern chemical twist on this are the molecules known as sepulchrates. These are examples of cage or chelate compounds where an ion (or molecule) is trapped in a molecular cage, or in this case entombed.



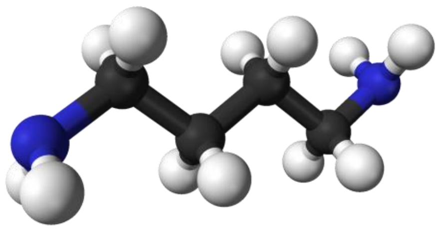
Cobalt(II) sepulchrate

A *columbarium* is a place where niches are used to store human remains, bones or ashes, and comes for the Latin word for dovecote (Latin *columba* = pigeon.) Another prefix meaning death is *thanato-,* so thanatology is the study of death. As a suffix we find it, for example, in euthanasia, the causing of an easy or painless death.

Some molecules are specifically formed by dead bodies as they decay, usually with distinctive and disgusting smells, thus we have *cadaverine* and *putrescine*. Putrescine and putrid comes from the Latin *putrere* = to rot, the smell of death, hence putrefaction. Cadaverine comes from the Latin *cadaver* = dead body. Another word for this is corpse (Latin *corpus*), but it also means a body in general, e.g. a corpus of knowledge. Both cadaverine and putrescine are diamines produced by the breakdown of amino acids. Cadaver dogs are sensitive to the chemicals produced by decaying bodies and are used to search for buried corpses.

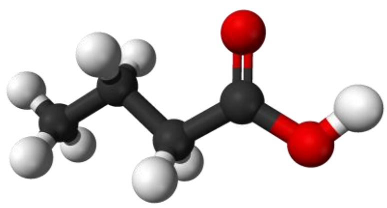


Cadaverine $(CH_2)_5(NH_2)_2$ 1,5-diaminopentane



Putrescine $(CH_2)_4(NH_2)_2$ 1,4-diaminobutane

Another interesting chemical of death is adipocere, known as grave wax, produced by the hydrolysis and hydrogenation of fats after death, and the word is a combination of the Latin for fat (*adipo-)* and wax (*cera*). A key precursor is butyric acid, named from butter and responsible for the smell of rancid butter.



Butanoic (butyric) acid $CH_3CH_2CH_2CO_2H$

□

Quirky Elemental Facts in Rhyme

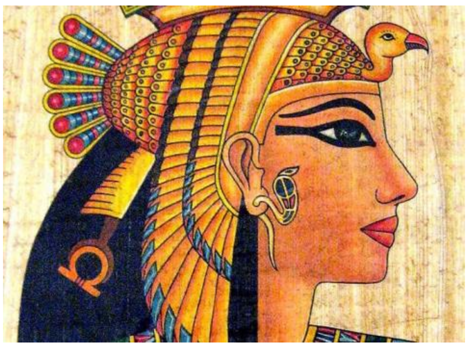
Antimony, Sb

Peter Davern peter.davern@ul.ie

Antimony's the metalloid to purge the gut, and how!
That glint in Cleopatra's eye, its sulphide did endow.

The Group 15 metalloid antimony sits in the periodic table's metalloid buffer zone, which is located between the vast expanse of metals to the left and the smaller clique of non-metals to the right.

Antimony is quite toxic for an element, but its toxicity was exploited during the Middle Ages to treat constipation. A person would swallow a pea-sized antimony pill, which irritated the intestines to cause a relieving, laxative purge! The offending (yet medicinally invaluable) pill would then be retrieved from the projectile-esque feces and retained for future use. Another type of purging effect could be produced using wine left standing overnight in an antimony goblet. Enough antimony dissolved in the wine to make the resulting potion a powerful *emetic* (a vomit inducer).



The fine black pigment form of the naturally occurring mineral stibnite (antimony sulfide, Sb_2S_3) has been known since ancient times. It's so black and so fine, in fact, that the ancient Egyptians put it to alluringly good use in cosmetic mascara and eyeliners.

Quirky Elemental Facts in Rhyme

Tantalum, Ta

Peter Davern peter.davern@ul.ie

When Ekeberg named tantalum, he'd Tantalus in mind,

'Tis soft 'n' dense, and hard to melt, and quite inert you'll find.

In 1802, the Swedish chemist Anders Gustaf Ekeberg (1767–1813) claimed the discovery of a new element. He named it tantalum (after Tantalus, a king in Greek mythology) because of its reluctance to dissolve in acids. Tantalus was condemned by the gods of Olympus for (among other things) daring to serve them the carved and roasted remains of his son, Pelops, whom he had earlier killed. Tantalus's punishment was to eternally stand partially submerged in a pool of water that quickly receded each time he stooped to drink. With this in mind, Ekeberg wrote, "This metal I call tantalum . . . partly in allusion to its incapacity, when immersed in acid, to absorb any and be saturated."

Tantalum is chemically very similar to niobium (which sits directly above it in group 5 of the periodic table). Both elements often occur together in nature and are then difficult to separate. For this reason, it took more than 40 years for the validity of Ekeberg's claim to be finally acknowledged.

Tantalum is a soft, silvery metal that's almost 50 percent denser than lead. It has the fourth-highest melting point of any metal (3,017°C), behind only tungsten (3,407°C), rhenium (3,180°C), and osmium (3,054°C). Tantalum is corrosion-resistant and also impervious to chemical attack, even from aqua regia[1].

1: Aqua regia, from the Latin for royal water, is a highly corrosive, fuming, yellow/red mixture of nitric acid and hydrochloric acid (1:3) capable of dissolving most metals, including gold.

Diary

2023

ASE Annual Conference
5-7 Jan.
Sheffield Hallam University, UK
ASE Annual Conference 2023 at Sheffield Hallam University | www.ase.org.uk

ISTA Annual Conference
31 March - 1 April
TUS Limerick
ISTA Annual Conference Branch Rota – Irish Science Teachers' Association

Eurovariety 2023
28-30 June
Tartu, Estonia
10th Eurovariety in Chemistry Education 2023 (ut.ee)

Chemistry Education Research and Practice
Gordon Research Conference
"Coordinating the Production and Consumption of Knowledge on Chemistry Teaching and Learning"
9 – 14 July
2023 Chemistry Education Research and Practice Conference GRC

ChemEd 2023
23-27 July
University of Guelph, Canada
ChemEd 2023 – calling all chemistry educators (uoguelph.ca)

ChemEd-Ireland 2023
'Green chemistry and the classroom'
21 October
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Amazing minerals: Quartz

The many forms of sulfur

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