Chemistry In Action!

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DISSI Special Issue

Contents #122

Disclaimer

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.

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Editor: Peter E. Childs peter.childs@ul.ie
Assistant editors: Marie Walsh, Maria Sheehan (web editor), Sarah Hayes, Anne O’Dwyer

Editorial # 122

Special DISSI Issues

UL has been involved in a number of EU-funded projects and previously we have had special issues focusing on two of these projects: SALiS (#97, Summer 2012) and TEMI (#107 Spring 2016). Each special issue consisted of an outline of the project and articles from each of the project partners, with examples of teaching materials. The idea was both to publicise the projects but also to inform Irish teachers and give them materials they could use in their classrooms. This issue is a special one devoted to the DISSI project: **Diversity in Science towards Social Inclusion.**

The project is led by Professor Silvija Markic, University of Munich (formerly from Ludwigsburg), with partners from Ireland, the UK, Slovenia, Macedonia and Germany. The special issue consists of an introduction from Professor Markic, followed by papers from the five partners. I was asked to give a plenary talk at the final conference in July and I have included this talk at the end of the papers.

The purpose of the project and this special issue is to make Irish teachers and those from other countries more aware of the issues surrounding Diversity, Equity and Inclusion (DEI) in Irish (and European) schools, particularly in STEM education. Anyone living and teaching in Ireland, especially at primary level, must be aware that Ireland has become increasingly diverse over the last 20 years, with significant immigration, most recently from Ukraine. This includes economic migrants from the EU but also large numbers of refugees, especially in the last 2 years from Ukraine. This has changed Ireland from a country with a relatively homogeneous demographic (white, Catholic) to a much more heterogenous population. The main non-national group used to be from the UK, it is now from Poland. In 2022 the estimates also show approximately 703,700 non-Irish nationals living in the State, accounting for 13.8% of the total population. (Population and Migration Estimates 2022 show population growth driven by large increase in migration - The European Migration Network (emn.ie))

In some urban Irish schools, non-nationals are in the majority and this presents significant challenges to schools and teachers. A major issue is language proficiency and many students are second language learners. Proficiency in the language of instruction is essential for successful learning in any subject, and STEM subjects have their own specific language issues. Like the poor, diversity will always be with us, and we must adapt to this new reality.

Peter E. Childs
Hon. Editor

Contents of #122

The main contents of this special issue are papers relating to the DiSSI project. The project is introduced by the Coordinator from Germany, Silvija Markic (p. 5). This is followed by a paper from Germany looking specifically at the issue of language diversity by Silvija Markic and Sarah Kieferle (p. 8).

The next paper from the Irish team at UL, Sarah Hayes and Genco Guralp, looks at pedagogies for teaching students from diverse socio-economic backgrounds, especially DEIS schools, using innovative teaching materials (p. 12).

A group that is often overlooked in dealing with diversity is that of gifted students. The Slovenian team (Luka Vinko, Luka Ribič, Miha Slapničar & Iztok Devetak) specifically addressed this group in developing teaching materials for teacher and student workshops (p. 19).

Jane Essex, Kirsty Ross and Ingrid Birnie describes culturally-responsive science outreach in Scotland (p. 25).

The team from Macedonia (Marina Stojanovska, Katerina Rusevska, Lambe Barandovski, Slavica Tofilovska, Vladimir M. Petruševski) used the 5E model for inquiry-based learning with ethnically-diverse groups (p.30).

Finally, Peter Childs (UL) gives an overview of various issues relating to DEI in STEM education, as a reflection on the DiSSI project (p.30.)

The final paper in this set is by Peter Childs, who was invited to give a plenary tak at the project's final conference in July, who gives some reflections on the diversity, equity and inclusion mobement (p. 41).

Some of the regular features have been left to the next issue as this is a special issue for the DiSSI project.

We have included Adrian Ryder's latest Chemist you should know, William Champion, who was the leading Wuropean manufacturer of zinc in the 18th century (p. 54).

There is also another Chemlingo by Peter Childs looking at Alchemical fossils in our language (p. 59).

The second part of the Sulfur Story on the many forms of sulfur can be found on p. 60.

Final conference

Acknowledgements

The presented work was part of the project "DiSSI – Diversity in Science towards Social inclusion – non-formal education for students' diversity" that is co-funded by the Erasmus+ Programme of the European Union, under the grant number 612103-EPP-1_2019-1-DE-EPPKA3-IPI-SOC-IN. We would like to thank the European Union for its financial support. The European Commission's support for the production of this publication does not constitute an endorsement of the contents, which reflect the views only of the authors, and the Commission cannot be held responsible for any use which may be made of the information contained therein.

Education News and Views

New STEM Professor at UL

Dr Geraldine Moonie Simmie has been appointed Professor of STEM Education at the University of Limerick and Director of Epi*Stem. She was formerly the acting Director of Epi*Stem. Geraldine is a former Chemistry teacher and is well-known to Irish science teachers. She brings a deep knowledge of the Irish education system and STEM education to the role.

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New HQ for Engineering Technology Teachers Association

Dundalk to become national centre for STEM in Ireland | Newstalk

6/5/23

STEM teaching in post-primary and Further Education and Training (FET) is due to get a boost with the establishment of new teaching headquarters in Dundalk.

The new Engineering Technology Teachers Association (ETTA) headquarters will be located at the Advanced Manufacturing Training Centre of Excellence (AMTCE).

A memorandum of understanding was signed this morning, which will see Dundalk become the national centre for teaching STEM, the name that's collectively given to Science, Technology, Engineering and Mathematics. Under the new arrangement, teachers will study and liase in the centre with leading personnel in the sectors to develop expertise.

The development will assist in projecting Ireland as a leading country for science and technology innovation.

The AMTCE will also provide active support for ETTA projects that encourage post-primary and FET learners to engage with advance manufacturing, STEM, IT, and other related subject areas.

Louth/Meath Education Training Board CEO Martin O'Brien said the new centre will contribute hugely to creating the next generation of top-class Irish engineers.

"What this centre will do is it will enable our young people to experience advanced manufacturing, to take that up as a career, to present themselves to those kind of courses at third level," he said.

"Then industry can become more lean, more efficient, be able to withstand the global shocks and become more sustainable."

"Together, we will explore joint funding opportunities and the launching and promotion of initiatives in our schools and further education that will increase access and participation in engineering and technology initiatives."

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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

Bookings:

https://www.eventbrite.ie/e/chemed-ireland-2023-conference-tickets-618919182937

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DiSSI: Diversity in Science towards Social Inclusion

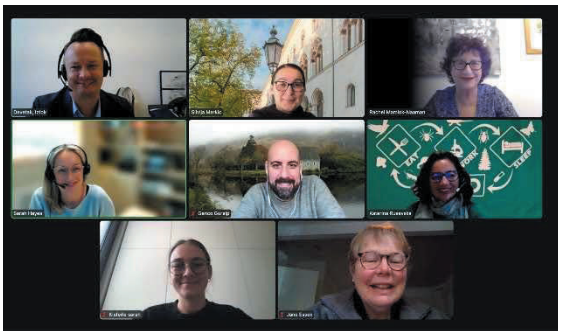
Silvija Markic
Ludwig Maximilian University of Munich, Germany
s.markic@cup.lmu.de

The group of researchers in this project came together following their idea of an ideal science and chemistry education, offering science and chemistry to all the students. For a long time, the researchers involved in the DiSSi Project were all working on their own research focus and following the need of their native educational system. During one science education conferences, we saw the need to join our forces and competences and start a project which will provide the social inclusion of all students in science education.

The DISSI team meeting in Ljubljana, Slovenia

The overarching purpose of the DiSSI project is to contribute to an equality of opportunities in science teaching. DiSSI focuses on science learning since science knowledge is a key competence for a wide range of jobs in engineering, industrial research, and many other fields that form the heart of the economy. Thus DiSSI can be conceptualized as a contribution to Science Education for Responsible Citizenship as it has been defined in the EU report (EC, 2015). This will help to educate students for shaping our future in responsible ways based on scientific evidence as requested in the Paris Declaration (Eurydice, 2015).

One of the main goals of science lessons is gaining content knowledge. However, science knowledge is unevenly distributed and so is the access to this important section of the job market. A major challenge in science education is to support every student in a way that he or she can learn science in the best possible way. This has been emphasized by the European Commission’s expert group for science education. Science education should be an essential component of a learning continuum for all. The expert group defined a need for *“innovative teachers’ strategies to address the diversity of students”*. If diversity is insufficiently addressed, this results in (i) social inequalities in the access to a wide range of well-paid jobs, leading to social tensions; (ii) low-achieving students who do not acquire Scientific Literacy, which is central for becoming responsible citizens in our society shaped by science and technology; and (iii) gifted students who cannot fully contribute to society because they do not develop their full potential. The DiSSI project aims at contributing to a greater equality of chances for all students through the development of science teaching approaches that address diversity.



The DISSI partners on a Zoom call

Thus, with the DiSSI project, we seek to develop and implement innovative methods, tools, and activities to foster inclusive science education. This will be achieved: (i) through the development of good practice material and further innovation in concrete learning settings; and (ii) through the support of pre- and in-service science teachers in addressing different dimensions of diversity in science classes and reflecting with them on the impact of diversity on science learning. Since the support will take place in concrete learning settings, both the teachers and the students will profit from this process.

It is especially those groups of students who differ from the 'norm' who are disadvantaged in science. This is true for students with a lower socio-economic status, those who speak other languages at home than the language of instruction, or who belong to ethnic minorities. Unexpectedly, also the group of gifted students also tends to be disadvantaged and underrepresented in science. Some work in this area in science education already exists. In the following, we will discuss major findings on these disadvantaged groups in science.

After the difficulties caused by the COVID pandemic, all the partners continued with even more enthusiasm and joy at our work.

In the first part of the project, each partner focused on one of the named dimensions of diversity. Here in this collection of articles, different methods and tools will be presented which the partners developed, implemented, and evaluated in their own countries In the final step of the project and after the exchange of the results from the first part of the project, the partners used the strengths of the group and adapted the knowledge about the methods and tools from others in the group to make their own non-formal education materials inclusive in the meaning of Science for All.

Some examples of the work in different kind of non-formal education can be found in the photos below.

DiSSI – some activities in the frame of non-formal education

In this special issue, we would like to present the work of the DiSSI-partners, which will show how it is possible to work with different group of students. We hope our work will help you and your students in learning Science.

Save the date:
The DiSSI final conference will be on online on July 3rd, 2023, between 9:30 and 18:00 (CET). For join us use following link:
https://lmu-munich.zoom.us/j/66800832824?pwd=Ri80NDAzT3I4VmhpNkNsWktNb1pEdz09
Meeting-ID: 668 0083 2824
Kenncode: 234134

References

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Eurydice _ Europäische Exekutivagentur für Bildung und Kultur, Eurydice, Promoting citizenship and the common values of freedom, tolerance and non-discrimination through education : overview of education policy developments in Europe following the Paris Declaration of 17 March 2015, Publications Office, 2016, https://data.europa.eu/doi/10.2797/396908

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Combination of language-sensitive methods in chemistry classes

Silvija Markic[a] and Sarah Kieferle[b]
[a] Ludwig Maximilian University of Munich, Germany, s.markic@cup.lmu.de
[b] Ludwigsburg University of Education, Germany

Introduction

With increasing immigration in the last decades, both diversity of society and the students in educational institutions has increased. Learning groups are not to be seen as homogeneous as in the past. This is especially true for students` linguistic competences. For chemistry education, this means in concrete terms that subject skills are always taught in a context of very different and mixed abilities and high heterogeneity of language (Childs *et al.,* 2015).

Differences in students' linguistic competencies are a part of a political educational discussion for already more than 20 years. For a longer time, bigger worldwide studies such a TIMSS and PISA show the relevance of language in science education (Lynch, 2001). Thus, in the last few years a focus on teaching and studying language in chemistry classes is becoming the focus of chemistry education researchers. As a result, different methods for language-sensitive and language-supportive chemistry teaching have been developed and spread around the world. A repertoire on different methods has been collected and their implementation evaluated. A large number of such methods can be found in Markic *et al.* (2013).

Starting from here, the question arises as to whether the single methods on students` linguistic competences for a class with diversity can be seen as enough and successful. We all know that not all methods are used by and are helpful for all students. From this point of view, a gap in chemistry education research can be described as an exclusive focus is on one single method or tool and limited knowledge about the combination of the different methods. Thus, the heterogeneity of the students` competences was not considered.

Combination of language-supportive methods and tools

Starting from the gap identified above, the DiSSI team in Germany worked on a proper combination and composition of different methods and tools, which can enable students to participate actively, work cooperatively and follow an approach of open inquiry in a non-formal education in a form of student laboratory. The results of the study can be seen in Kieferle and Markic (2023). In the following, the listed tools and methods can easily be adapted in schools.

Labelled workplaces

For student-centred work in a laboratory, it is important that students are familiar with the equipment that is supposed to be used. From their everyday life, students are not familiar with scientific equipment and don't use their names outside the chemistry lesson. Thus, the naming of scientific equipment seldom becomes a part of our students' active vocabulary. However, to participate actively in chemistry lessons this vocabulary is needed. Students need to communicate about the experiments, they need to write down what they do in the class and be able explain it to each other.

A simple method for enabling students to use the names of the equipment is the labelling of the workplaces in schools. Such an example can be seen at Figure 1. Figure 2 shows how a single drawer can be labelled. By using this method in the classes, students can see how the equipment looks, what is its name, and also the plural of the word. Thus, illustrated and labelled workplaces support dealing with scientific terms and laboratory equipment.

Figure 1: Labelled workplace with names and pictures

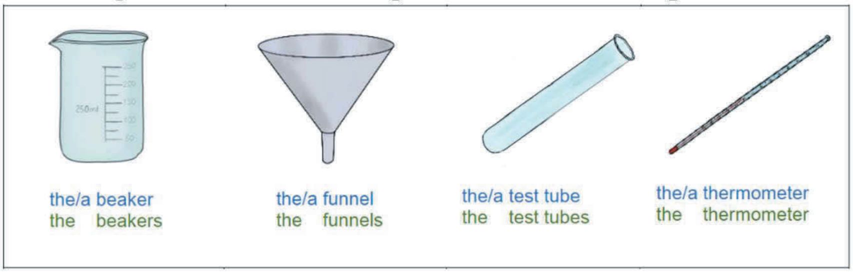


Figure 2: Example of the labelling of a drawer

Graded Tip Cards

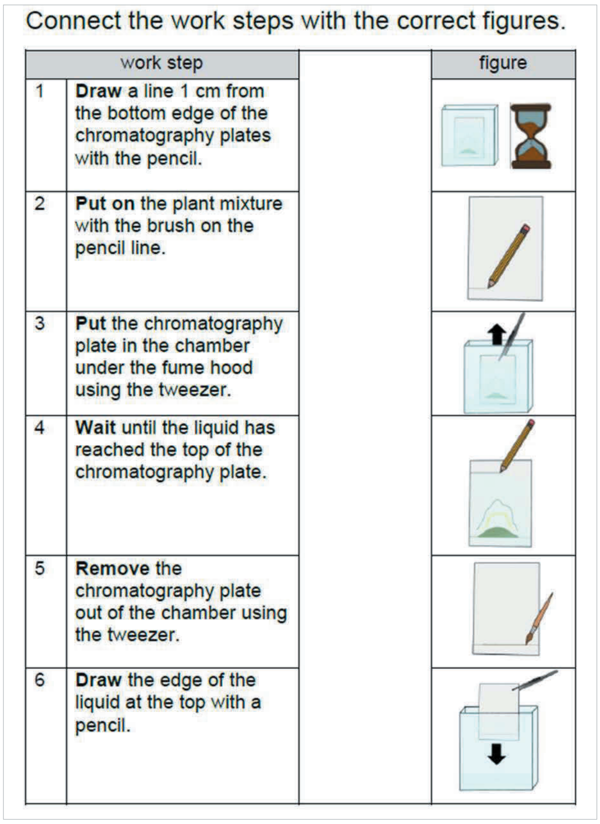
Another tool, which can enable students both to participate actively in the class and work within their linguistic abilities, are the graded tip cards (see Figure 3). Here, students are supported with little hints or even structured experiment instructions, while they conduct experiments. Complex scientific issues can be answered step by step with the help of graded tip cards. The graded tip card can be organized differently focusing on the need of the different students. Differentiation within a learning group is possible through individual support (Affeldt *et al.*, 2019; Markic *et al.*, 2013). On a card a sentence patterns, block diagrams, and sentence starters can be presented to help students to formulate observations and findings or in doing experiments. Graded tip cards focus on the different linguistic competences of students.

If a topic for the students is to write an instruction for an experiment, this can be a great challenge for some students and for other students not as much. Thus:

- A first tip card can contain a list of equipment which students need to use.
- A second tip card can contain a sentence, which students can use to write down a procedure.
- A possibility for a third tip card is presented in Figure 3, where the sentences which are part of the procedure are given in the right

order and need to be connected to the drawings of the single steps.

- A fourth and last card can describe the written procedure with the drawings of each step in correct order.



Connect the work steps with the correct figures.

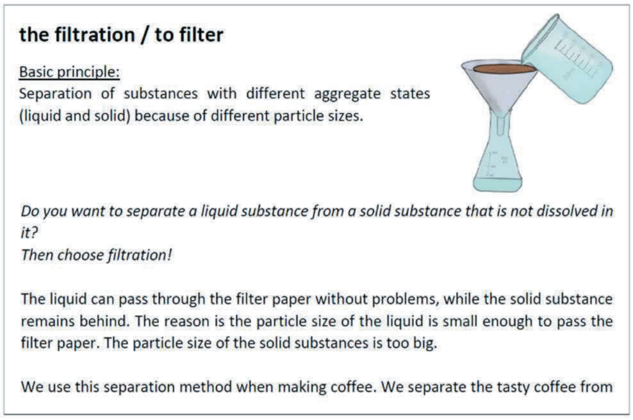
work step			figure
1	**Draw** a line 1 cm from the bottom edge of the chromatography plates with the pencil.		
2	**Put on** the plant mixture with the brush on the pencil line.		
3	**Put** the chromatography plate in the chamber under the fume hood using the tweezer.		
4	**Wait** until the liquid has reached the top of the chromatography plate.		
5	**Remove** the chromatography plate out of the chamber using the tweezer.		
6	**Draw** the edge of the liquid at the top with a pencil.		

Figure 3: An example of the graded tip cards

Glossary

While learning a foreign language our students often use a glossary to remember but also revise the new vocabulary. A glossary is a list of words and their meanings. A similar technique can be used in chemistry lessons as well. A glossary can be used in the form of a collection of cards in a box, located in the classroom.

It is not necessary that all students develop their own glossary. It is easier to manage if the whole class participate in the creation and the collection of the glossary cards. Thus, it can be seen as their joint work and can be used by the whole class. An example of a card for a glossary can be seen in Figure 4. The card can present a description and short explanation of scientific terms or methods.



the filtration / to filter

Basic principle:
Separation of substances with different aggregate states (liquid and solid) because of different particle sizes.

Do you want to separate a liquid substance from a solid substance that is not dissolved in it?
Then choose filtration!

The liquid can pass through the filter paper without problems, while the solid substance remains behind. The reason is the particle size of the liquid is small enough to pass the filter paper. The particle size of the solid substances is too big.

We use this separation method when making coffee. We separate the tasty coffee from

Figure 4: An example of a glossary card

Reflection

At the first glance, the usage of the different methods and tools focusing on the differences in linguistic competences of students can be seen as a lot of work. It is not to deny that this is true. However, the work does not need to be done only by the teacher. Labelling an equipment in the chemistry laboratory can be also done by a group of students in the framework of project work. This will also give a feeling of an ownership to the students for this work. The laboratory will be seen as their place to work, where they had a chance to "design" it as well.

The same is true for the glossary. Each class can develop such a glossary for themselves. The focus can be different and separated by the topics they study. One box can be on scientific methods (as presented in Figure 4), and another box with the cards for glossary can have a focus on acids and bases, for example.

Finally, the consideration of students` linguistic competences in your own chemistry class is your own decision as the teacher, but the work can be shared with the students.

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Biography
Sarah Kieferle is a PhD student at the Ludwigsburg University of Education. Here she studied German, chemistry and biology for the lower secondary school and completed her internship. She holds second state exam in Germany. In her dissertation, she develops and researches inclusive learning environments for the secondary school student laboratory.

Silvija Markic is a professor of chemistry education at the Ludwig Maximilian University in Munich. Until April 2022 she was a professor for scientific learning at the Ludwigsburg University of Education. She studied chemistry and mathematics for grammar school and was senior researcher at the University of Bremen until March 2017. Current key areas of work include learning scientific language, teachers' knowledge of language, dealing with linguistic heterogeneity and cultural diversity in chemistry classes.

□

Science Education Pedagogies for Students with Diverse Socio-Economic Status

Genco Guralp and Sarah Hayes
genco.guralp@ul.ie and sarah.hayes@ul.ie
University of Limerick, Ireland

Introduction

Many studies demonstrate the general value of diversity for science, and the importance of addressing the needs of a diverse student population is noted in science education as well (AlShebli *et.al.,* 2018) (Mansour & Wegerif, 2013). Yet, what still needs to be emphasised is that diversity is a holistic notion, in other words, diversities in ethnic, cultural, linguistic, or socio-economic status do not exist in isolation. The holistic dimension of diversity can be seen to be a version of what the feminist legal scholar Kimberlé Crenshaw refers to as "intersectionality." Working on the discrimination experienced by black women in the USA, Crenshaw argued that precautions taken against discrimination on the basis of identity politics, neglected the ways race and gender interacted in the experience of Black women (Crenshaw, 1991). The DiSSI project is based on the observation that a similar dynamic of intersectionality operates in educational contexts, and therefore proposes to meet this crucial need in science education today by providing pedagogies that deal with this issue. The DiSSI project aims to generate pedagogical best practices that can support teachers in addressing diversity in a holistic manner in dealing with students from various diverse backgrounds. As the DiSSI Ireland team, our main emphasis is on diversity stemming from s*ocio-economic status*. In the contemporary context of global immigration and climate change, there are considerable challenges in promoting and sustaining interest in science among students from low-socio economic backgrounds. The activities which DiSSI Ireland developed aim at making authentic science contexts accessible to students from backgrounds which are traditionally excluded in science education. The DiSSI Ireland team is based in the Bernal Institute at the University of Limerick, and we operate as part of the Education and Public Engagement unit of the Science Foundation Ireland Research Centre for Pharmaceuticals. In our work, we developed a set of six workshops that incorporate various aspects of scientific knowledge, including argumentation, nature of science, experimentation, design, and collaboration. We have also run a 10 week workshop as part of a citizen science project. The over-arching aim of our workshops has been to engage students with authentic science activities that have social relevance.

The Concept of Science Capital

The concept of Science Capital constitutes the main theoretical tool in guiding the formation of our pedagogical practices as well as in analysing our results. This concept was first developed by Louise Archer and colleagues in their researches on the science aspiration patterns of post-primary students. The concept of Science Capital, which is built on Pierre Bourdieu's pioneering research on symbolic and cultural capital, aims to explain patterns of inequality among students that, despite various measures taken over years, has been "stubbornly resistant to change." (Archer *et. al.* 2015, p. 923.) Archer and colleagues understand Science Capital as science related forms of social and cultural capital that have the potential to inform the science identity and science aspirations of a young individual. These authors argue that students with "high" Science Capital tend to aspire to study science, and continue to science-related careers.

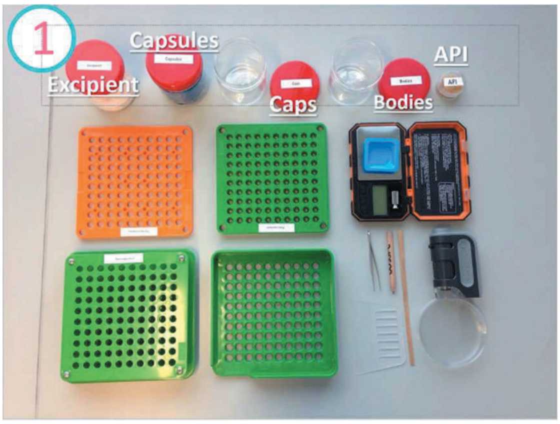
Although in their earlier work Archer and colleagues left the question on whether Science Capital could be augmented open, in later publications they assumed a more explicit stand and developed a Science Capital Teaching Approach (Godec *et. al*., 2017). The main ideas in this approach include "personalising and localising, eliciting, valuing and linking and building the Science Capital dimensions" (Godec *et. al*. 2017, p.17). Here the Science Capital dimensions include symbolic and cultural capacities and experiences such as scientific literacy, science related media consumption, or participation in out-of-school science activities (Godec *et. al*. 2017).

Non-formal Intervention in a Low-Income Neighbourhood school

In our workshops, we worked with students at an urban post-primary school in the city of Limerick. The school has the DEIS (Delivering Equality of Opportunity in Schools) status. DEIS schools differ markedly from non-DEIS schools in terms of the social class background, parental education, household income and family structures of their students. These schools have a higher concentration of disadvantaged students than other schools and also cater for more complex needs, with a greater prevalence of students from Traveller backgrounds, non-English speaking students, and students with special educational needs. In our methodology, we follow a design-based research (DBR) approach. (Bakker & Van Erde, 2015; Barab, 2006; Flynn et. al., 2018). After an initial design and implementation, the workshops are modified on the basis of evaluation of the previous iterations. We have run 3 iterations of the workshops, aiming to build innovative practices in the informal/non-formal sector for a diverse body of students.

The Workshops

Medicine Maker: The Medicine Maker workshop is a fully structured activity that allows the participants to engage with a hands-on activity in the context of pharmaceutical science and manufacturing. (McHugh *et al*., 2022) The workshop uses a kit composed of several items that enable the students to make their own medicine capsules.



The kit contents for Medicine Maker

In order to make the relevance of pharmaceutical science explicit for the students, the workshop begins by giving basic information about the pharmaceutical industry in Ireland. We then discuss the basic elements of drug manufacturing and different types of medication delivery (such as oral tablets or capsules) and the basic chemistry of medicine manufacture. Here we introduce the concept of a crystal and show students the crystalline structure of everyday items such as aspirin or chocolate. The aim of the initial presentation is both to set the stage for the hands-on activity, as well as capture the interest of the students. We then provide a step-by-step presentation of the activity, beginning with a slide that identifies all the items that will be used during the activity. All items that are presented to the students are labelled and the basic terminology used during the activity is available on the slides.

A workshop in progress

During the workshops, students use several pill plates to fill the capsules provided with flour and brown sugar, which represent the excipient and the active pharmaceutical ingredient, respectively. The workshops end with a discussion of several topics, including, quality control, the importance of pharmacovigilance, and only obtaining medicine through doctors' prescription from pharmacies. Medicine Maker thus combines authentic science elements, with topics from science and society in an inquiry-based fashion. Medicine Maker can be developed in several ways. In one iteration of the activity, the students were asked to produce their own leaflet for the "medicine" they produced.

Gross Germs and Bizarre Bacteria: Gross Germs and Bizarre Bacteria is a moderately structured activity that is composed of two components. Students first conduct an activity that emulates handwashing by using latex gloves and paint. During this activity, the moderator first asks the students to put on the gloves, and then squirts a small amount of paint on their hands. The students are then asked to close their eyes and "wash" their hands as they normally do. After about a minute, the activity ends and students observe whether there are any areas in their hands that were paint free. This leads to a discussion concerning hand hygiene and how soap kills bacteria. In the second part of the activity, students make their own hand gel, using Carbopol (a thickening agent for gels and lotions), sodium hydroxide, and ethanol. The science core of the activity consists in weighing the correct amount of Carbopol and NaOH (in grams and milliliters, respectively) and measuring the pH level of the gel, and carefully adding NaOH to the compound until it reaches a level close to the skin pH of ~5.5. In order to keep the hand-gel homogeneous the ethanol must be added slowly to the gel. There are several aspects of science that are communicated to the students in this activity. These include how actual experiments work, as many students aim to get the 25 grams exactly right, and find out to their surprise that there is always an error in the measurement and the result cannot be "exactly" 25 grams. They also experience that in most cases, experiments do not work, and one needs to start over. Finally, this activity also shows the applied nature of science, as the relationship between "pure" scientific knowledge and a public health product is also explored.

Space: Fact-off Activity and NASA Survival Exercise: Research shows that inquiry-based hands-on activities are very successful in promoting interest in science among students from low-income socio-economic backgrounds. (Calabrese Barton *et. al.* 2018) However, during the first iteration of the workshop program, we observed that this type of fully to moderately structured activity did not appeal to all students. As the aim of DiSSI is to promote diversity, one solution to this problem is to increase the variations of the activities. The Space-themed *Fact-off* and *NASA Survival* activities aim to foster collaboration and debate skills in the students which also allows them to explore *Nature of Science* topics and questions such as: what a scientific fact is, how a fact is different from a theory, whether scientific facts are open to revision, how peer review works, and how scientists argue for their views. Similar to the *Gross Germs and Bizarre Bacteria* activity, this space-themed activity is also a two-tiered one, where the first activity prepares the ground for the second one. In the first part of the activity, students are asked to work in groups of two and list a number of facts on space and the universe. After working in their group, the students share a "fact" with the whole class, and other students are given the opportunity to contest the fact the group proposes, i.e., the objecting group has to provide good reasons why the alleged fact is actually incorrect. The instructors and teachers act as judges and depending on the outcome either the original group or the objecting group is cut from the activity, until a winning group is declared. During the second half, students are given a scenario of being a member of a group of astronauts that crash landed on the moon and are asked to rank a list of items that they may need to survive. After individual work on the ranking, a class ranking is obtained through group discussion and debate.

Animal Ethics in Research: One of the key aspects of science that science educators may make use of in order to promote interest among low socio-economic background students, is that science is a value-laden activity, and in many cases, scientists need to make value-judgements in their research. This is most prominent in the fields of biology and medical sciences, although some researchers have argued that even fundamental physics is not immune from value judgements. Understanding this aspect of science is crucial for students as future members of an informed public and the *Animal Ethics* activity aims to use a debate activity to promote this goal. The activity begins by a presentation on the publicly well-known cases of animal usage in science such as *Laika*, a dog that was sent to space as part of the Soviet space mission, or the sheep *Dolly* that was cloned by researchers at the University of Edinburgh. We then go through a couple of cases where animal research has contributed to society and the types of ethical dilemmas this research poses. At the end of the presentation, students are divided into two groups and tasked with debating the question: 'Is it morally OK to conduct research on animals?' Groups may choose which side they will defend, or the teacher may make this choice for them (e.g., if both of the groups wish to go for or against the issue of animal research.) The groups are given a class period in which they discuss and list the arguments they will present. Then two "spokespersons" from each group will "pitch" their respective positions in a short presentation. Afterwards, a group debate will ensue wherein the students will try to convince the teacher and the researchers to their views.

Crystal Drop: The Crystal Drop activity, which is modelled on the well-known egg-drop experiments, is an open-ended and minimally-structured activity. Similar to the other workshops above, the activity begins with a short presentation on crystals, including different types of crystals, unexpected usages of them in daily life (such as diamonds in saws or graphite in the tip of pencils).

Students at work on their Crystal Drop design

This is an interactive presentation with most of the slides having large pictures of crystals and no words. During the presentation, the instructor asks the students to guess the crystal pictured and where it might be found. After the interactive presentation, the Crystal Drop Challenge is introduced. The Crystal Drop Challenge consists in wrapping loosely attached cubes of sugar crystals such that the attached cubes stay intact after the entrapment is dropped from a certain height. Students are provided with a variety of materials and are asked to firstly design a prototype (this can be done in groups) and explore its potential strengths and weaknesses. Following this, they will complete and label a final design drawing that they must follow when they are building their protective device. Students will be asked to explain their creation to the rest of the class for approximately thirty seconds to one minute and give a name to their device. All students are asked to fill out a recording sheet where they will predict if their peers' devices will be successful in protecting the crystal and explain their reasoning. Finally, the devices and crystals will be dropped from a height. Any adult can stand on a table or chair that can bear their weight and let the crystals fall. It is advised to have scissors at hand to cut open the devices so that the students can see the results.

Do We See through a Microscope?: The concluding sixth workshop of the series aims to bring several elements that are introduced in the previous workshop together, using history of science and technology as a unifying theme. In this activity, the instructor presents the history of the invention of the microscope and situates this history in its social and economic context of the 17th century Dutch empire. We focus on the contribution of Antonie van Leeuwenhoek, who was a textile merchant whose interest in microscopy was mainly motivated due to his desire to understand the thread quality of the fabric. This historical contextualisation of science and technology aims at showing the students how practical or economic concerns may be a motivation for developing fundamental scientific instruments. The presentation continues with the basic optics principles behind the microscope and its similarity to the telescope.

Student-contructed microscope using their cell phone camera

Here the instructor can also mention how the invention of the telescope was crucial for the Copernican view of the universe to gain prominence and Galileo's famous "conflict" with the Church authorities. Thus, a cloth merchant's interest in fabric quality may be related to a major revolution in scientific thinking that had many social and political repercussions! After the interactive presentation, the students build their own microscope using a kit composed of a cardboard tube, a lens, and a pencil that is used for sharpening the image by mechanically moving the slide back and forth. The students use their cell phone cameras to observe several slides that the instructor provides (the slide is an extra item that is not part of the kit provided to the students.)

Crystal Clear—A Citizen Science Activity

The DiSSI Ireland team collaborates with co-investigator Dr. Sarah Guerin's (Lecturer in Physics at UL) SSPC "Crystal Clear" project. This work aims to build a standardised kit to develop environmentally-friendly bio-crystal molecules that are piezoelectric using a citizen science activity. In this project, we worked with Transition Year (TY) students. TY is an optional year between the junior and senior secondary cycles in Ireland (ages 15-16), which is not examined and has no set curriculum, allowing teachers an opportunity to innovate. At the beginning of the project, the students visited the SSPC Education and Public Engagement (EPE) Lab at the Bernal Institute and began a 10-week period of testing different methods of crystal growing. During these weeks, the students learned basic information about the nature of crystals, the science of crystal growth, piezoelectricity and its applications. At the lab, they tested different growth methods through observations, and worked towards developing a standardized kit that will be user-friendly and can be packaged and sent to schools for implementation. The following stage of this project will send the Crystal Clear citizen science kits to Irish schools to enable students and teachers to evaluate the levels of reliability of amino acid sensors and their material properties via a citizen science approach. The dual approach of involving students, teachers and scientists in both the creation of the kits and national testing will ensure a truly authentic citizen science approach incorporating co-creation and development principles.

Conclusion

One challenge of non-formal approaches in science education is that these interventions tend to be 'one-off" and it is difficult to see to what extent they have a lasting influence on the students' thinking. To achieve a more impactful form of intervention, we conducted a six-week long workshop series with first year post-primary students, and a 10-week thematic science activity with a class of TY year students. The hands-on nature of the activities proved to be appealing to students from low socio-economic backgrounds, who do not have a specific positive attitude towards school science or high-level science aspirations. Several students for whom the hands-on activities were not particularly appealing did participate in the debate and group discussion activities, which shows the importance of varying the pedagogical forms to reach students from various diverse backgrounds.

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Biography

Dr Sarah Hayes is the Chief Operating Officer of SSPC: the Science Foundation Ireland Research Centre for Pharmaceuticals. She has more than 13 years' experience working at the interface of academia and industry, working in research, education, operational management and large-scale project management in industrial, academic, national and international settings. Sarah has previously held the position of SSPC Associate Director for Academic Partnerships and Public Engagement, and prior to that held positions in Mary Immaculate College, the University of Bremen and University of Limerick. A well-established Principal Investigator (PI), Sarah has significant experience in managing multinational and multi-sectoral R&D projects, having been awarded more than €7.3M, with €1.2M directly to Sarah as PI for her own research portfolio. Sarah established SSPC's award winning bespoke industry-academic internship programme linking the PhD curriculum with industry sector needs, *including the delivery of trainee industrial placements.*

Dr Genco Guralp is an Assistant Professor of Philosophy at the San Diego State University (USA) and a Postdoctoral Researcher Science Education at the University of Limerick (Ireland). He holds a Ph.D. in philosophy from Johns Hopkins University. His main research areas include the history and philosophy of science, science education, and public engagement with science. He is currently involved in the ERASMUS+ DISSI project—Diversity in Science towards Social Inclusion—with a specific focus on developing pedagogical best practices in informal and non-formal contexts for students from low-socio economic backgrounds. His work has appeared in the European Journal for Philosophy of Science, Studies in History and Philosophy of Science, and various edited volumes.

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The DiSSI team meeting in Limerick

Gifted students and chemical education in informal learning environment – DiSSI approach in Slovenia

Luka Vinko[1], Luka Ribič[1], Miha Slapničar[1,2] & Iztok Devetak[1]
[1]University of Ljubljana, Faculty of Education, Kardeljeva ploščad 16, 1000 Ljubljana
[2]BEC Ljubljana, General Upper Secondary School, and Veterinary Technician School
Corresponding authors' email: luka.vinko@pef.uni-lj.si

Abstract

Students' giftedness, which is a complex, developmentally dynamic, and contextual phenomenon, is something teachers encounter every day. In the classroom, they often meet students who have exceptional potential or achieve very high learning goals. Because the gifted students are a special learning group, the chemistry teacher must introduce teaching methods and learning and teaching approaches that encourage the gifted students to develop their chemical knowledge according to their potential. One such approach may be inquiry-based learning, in which students participate as active researchers, resulting in the development of scientific competencies at a level beyond the usual scope of lower and upper secondary chemistry curricula.

Giftedness in science and/or chemistry

Gifted students are not always able to solve complex problems in science in general. Often, a more specific talent for science is shown within the sciences, such as in chemistry, biology, or physics. Enrichment and acceleration programs are possible approaches for supporting gifted students, including those in the field of chemistry. The former approach allows gifted students to extend their learning beyond the scope of the curriculum, taking into account individual differences (e.g., research science camps, various chemistry competitions, research assignments at institutions that are not part of the school environment ...), while the latter approach allows acceleration of gifted students' development where it belongs, e.g., through early enrolment in school, skipping classes, etc. (Sumida and Ohashi, 2015).

Gifted students in chemistry show a high level of readiness and interest in learning new chemistry content. In learning this content, they show good concentration skills and metacognitive maturity. They use terms related to chemistry to describe chemical concepts and phenomena, and in this sense, have an extensive natural vocabulary. Understanding of chemical concepts by gifted chemistry students is quick, rapid, in-depth, and of high quality, and does not include incomplete- or mis-conceptions. They are the only students who are able to recognise these among their peers during a discussion and point them out (Taber, 2010). The gifted in chemistry can easily connect new concepts with existing ones and to the natural science (chemical) phenomenon they are describing. They are able to think ahead and make mental leaps at intermediate and, for them, less important levels, in building their understanding of a concept. They quickly understand the direction in which the research of a chemical phenomenon should go and can determine the outcomes of research in advance. The competencies of the gifted in chemistry extend to the ability to make chemical and mathematical models of a given phenomenon and to make creative and valid explanations of chemical phenomena. They are challenged by chemical problems placed in the context of real-life situations, and they connect the results of solved chemical problems to the new context without difficulty. They are capable of abstract thinking, which helps them identify patterns in data where the connections between them are not clearly visible. On this basis, they propose several alternative strategies for checking predictions or collecting data during experimental work (Gilbert and Newberry, 2007).

Gifted students like to set up hypotheses and manipulate variables in experimental research. They work persistently, perform their own activities, and create a high-quality product. Upon completion of a research paper on a particular chemical content, they are able to create an overview of the content, reflect on their thinking and learning as they seek to understand chemical concepts in depth (Benny and Blonder, 2018).

Enriching chemistry classes for the gifted

When teaching chemistry content, it is crucial for gifted students to explore chemistry concepts in depth and over a longer period of time. Chemistry lessons should be designed using the inquiry-based teaching and a learning approach that sparks interest and connects knowledge (Devetak and Ferk Savec, 2018). In this case, students are active researchers who investigate real problems and situations in the context of life situations (Devetak, 2017). It should be emphasised that inquiry-based learning is not just about solving a worksheet and writing down the results, but rather a process of building students' knowledge with the help of the teacher. The key emphases of inquiry-based learning are: (1) finding the research problem; (2) defining research questions and hypotheses; (3) identifying dependent and non-dependent variables; (4) planning the research and testing of variables; (5) carrying out measurements and observations with which we capture data relevant to the research; (6) predicting results; (7) analysing data and obtaining results; (8) establishing conclusions; (9) reporting; and (10) evaluating (Trna, 2014).

Inquiry-based lessons must be designed with emphasis on defining research questions, based on which the gifted students then analyse, synthesise, and evaluate information to find an answer. Gifted students should solve contextual chemistry problems in an interdisciplinary manner, using several different and interrelated domains. The teacher's role in this context is to encourage authentic scientific thinking and creativity. In doing so, the teacher makes sure that students take the initiative in making diverse choices about the content of the chemistry problem and in the overall planning of the work. In this way, we develop self-regulation in the gifted students - strengthening their ability to make decisions and to be self-directed in carrying out research activities. It is also an important factor for the teacher to ensure that gifted students are able to present the results of their work to an interested audience after completing the research (Devetak and Ferk Savec, 2018; Cabalsa and Abraham, 2020; Vroom Redden et al., 2020).

DiSSI informal learning activities for the gifted

The work of the Slovenian DiSSI group (https://dissislovenia.splet.arnes.si/) focused on gifted students in the field of science, especially chemistry, in the first phase of implementing DiSSI workshops in an informal educational environment. The gifted acquired chemical knowledge outside of school, at the KemikUm Center (https://www.pef.uni-lj.si/raziskovanje-in-umetnost/center-kemikum/), which has been successfully operated at the University of Ljubljana, Faculty of Education (UL PEF) since 2017. The function of the KemikUm Center is based on the connection between universities, schools and companies, with the aim of joint development of innovations, their use in chemistry teaching and learning, and optimization based on the evaluation of the activities carried out to contribute:

1) Transfer and successful use of development and research results in the educational process,
2) Improve the quality of teaching and learning chemistry according to the needs in school practice, local environment and in companies with activities in the field of natural sciences,
3) Promote young people's interest in chemistry and natural sciences, and
4) Improve awareness of the role of chemistry and natural sciences in society and the importance of sustainable development.

The advantage of informal teaching and learning of chemistry in such an environment as, for example, the Center KemikUm UL PEF is primarily the freedom to use different teaching approaches.

Various teaching approaches and examples of good practices were developed within the project. When preparing various activities, emphasis was also placed on cooperative learning to support the learning of all four, previously mentioned, groups of students. Activities developed for both lower and upper secondary school students include the following developed DiSSI learning modules:

1) “Forensics Science”
2) “Environmental Chemistry – hydrosphere pollution”
3) “Green Chemistry of the Future”
4) “Medical Active Substances in Pepper”

All learning modules are based on the principle of inquiry-based learning, which has proven as effective in teaching and learning chemistry for gifted students, as well as for others, but with certain adaptations to the learning approach.

At the faculty, we have conducted fifteen experimental workshops based on the above modules so far. The workshops have been attended by 310 lower and upper secondary students (aged 13 to 16) from schools all over Slovenia.

“Forensic sciences” module

With more than 160 participants, the "Forensic Science" module proved to be the most popular among lower secondary school students and teachers. Participants were presented with a fictional crime scenario with a description of the victim and suspects. Their task was to analyse the collected evidence by conducting various experiments combined with an inquiry-based learning approach and find out who among the suspects committed the crime. The workshop lasted an average of 4 school periods (45 minutes each) and consisted of four workstations covering different fields of forensic science, such as fingerprint analysis, unknown substance analysis, fibre analysis, and DNA analysis (Figure 1).

Figure 1. Evidence analysis.

At each workstation, students were provided with a worksheet. Each worksheet gave them a forensic problem to solve (see supplemental online material). They began by defining research questions and hypotheses, proceeded to design and conduct experiments, and concluded by discussing the results obtained and drawing appropriate conclusions. The module proved to be of equal interest to gifted and non-gifted students, with the gifted showing a more positive attitude toward inquiry-based learning.

The first few iterations of the workshop were evaluated and provided us with results, based on which some adaptations were made. We found that most students had difficulty in properly developing the research design and conducting experiments related to the workstation for analysis of unknown substances. We therefore used a learning approach from our project partners in Germany, who used tip cards with pictures for students with lower language skills to help them perform experiments. This adaptation had a positive impact on the way students conducted experiments. Another adaptation was the inclusion of game-based learning in our module. The game-based approach to chemistry learning was adopted from our North Macedonian partners. We used a simple puzzle that, when put together correctly under UV light, revealed the name of the suspect who had committed the crime. Students received a piece of the puzzle at each workshop based on the results of the evidence analysis (Figure 2). The adaptations had a positive effect on the non-gifted students' interest in learning forensic science, but not so much on the gifted students, who were more interested in the non-adapted module.

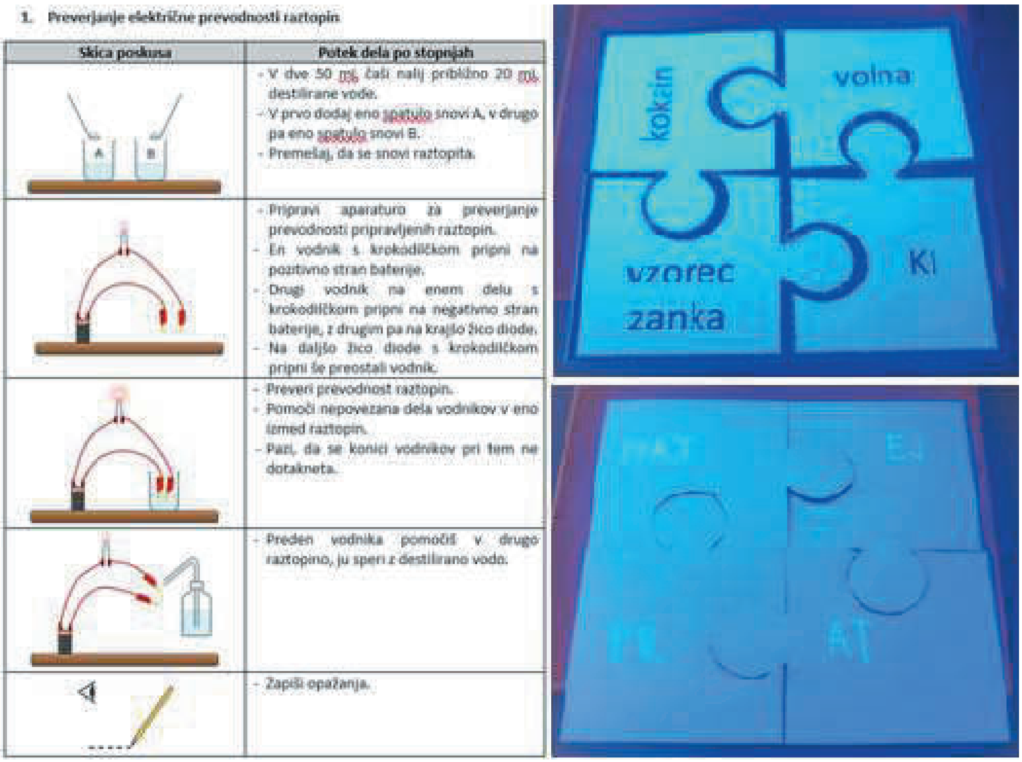

Figure 1. Module adaptations – experiments instructions for students who have difficulties reading (left) and developing the experimental design in the specific part of the inquiry-based teaching approach (right).

As part of the DiSSI project, Webinars were organised and conducted for in-service teachers of science, particularly chemistry, in which they learned about the theoretical basis of teaching and learning chemistry through inquiry, as well as aspects and adaptations of teaching chemistry to more effectively target gifted students in science, particularly chemistry. A total of 85 in-service teachers participated in the workshops. Participants also developed their own designs for DiSSI learning modules, which they later presented to their colleagues.

The DiSSI philosophy for teaching and learning chemistry was also presented to in-service science teachers who teach science, chemistry, and biology to students ages 12 to 17, and to elementary teachers who teach science to students ages 6 to 11. A total of 82 pre-service teachers participated in the workshops. They all conducted experiments focused on inquiry-based science education and developed ideas and prepared designs for their own draft DiSSI modules.

Conclusion

In Slovenia, a total of 82 pre-service and in-service teachers and 310 of their students participated in the ERASMUS+ DiSSI project. The main conclusion is that teaching and learning of chemistry content beyond the usual learning standards of the national chemistry curricula for lower and upper secondary schools can be applied in the informal learning environment at the university. Such an environment encourages students to learn additional chemistry concepts, such as forensic science concepts, which stimulate interest in inquiry-based chemistry learning approaches. Such approaches are also relevant for developing students' research competence according to teachers who participated in the DiSSI workshops. It can be summarised at the end, that the DiSSI project was a success in Slovenia.

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Biography
Luka Vinko is a teaching assistant of chemical education at the Faculty of Education, University of Ljubljana. His research focuses on students' environmental chemistry conceptions, teaching and learning chemistry in context

and inquiry-based chemistry education. He is a PhD student and teaches laboratory work for different chemistry courses.

Luka Ribič is a researcher at the Faculty of Education, University of Ljubljana. His research focuses on the use of digital technologies in chemistry education to improve learning outcomes and increase students' interest in chemistry. He is a PhD student and is currently working on projects mainly related to education for sustainable development.

Dr. Miha Slapničar is an assistant professor of chemical education at the Faculty of Education, University of Ljubljana. His research focuses on understanding redox reactions and the triple nature of chemical concepts. He is also a chemistry teacher at BIC Ljubljana, General Upper Secondary School and Veterinary Technician School.

Dr. Iztok Devetak is a full professor of chemical education at the Faculty of Education, University of Ljubljana. His research focuses on students' understanding of triple nature of chemical concepts, environmental chemistry, teaching and learning chemistry in context and inquiry-based chemistry education. He is also editor-in-chief of CEPS Journal.

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Culturally-responsive Science Outreach

Jane Essex[1], Kirsty Ross and Inge Birnie
University of Strathclyde, Glasgow, Scotland
1. Jane.essex@strath.co.uk

The Scottish team of the Erasmus+ project 'Diversity in Science towards Social Inclusion' (DiSSI) was tasked with investigating how culturally diverse groups could be attracted to science outreach activities. In this article we describe the principles behind the work we undertook, the activities that we ran and how they were received by people who took part in them.

Tools

We started by considering the features of inclusive teaching, which will transcend cultural boundaries, irrespective of the target group.

1. Teach science in the context of students' lives and show its relevance.
2. Show the pursuit of science as being embedded within diverse cultural contexts.
3. Present cultural diversity as a resource to be valued, rather than a problem to be corrected.
4. Teach for diverse learners, by deploying a range of teaching and learning strategies; this includes the use of student diversity as an aid to learning by facilitating group work. This must be facilitated by the setting of open-ended questions or tasks.
5. Promote understanding by using multiple modalities, e.g. sensory experience, pictures, speech, especially speech in various languages, reading, writing and drawing.
6. Focus on process, rather than the outcome, of knowledge creation, both historical and current.
7. Present science as a way of constructing meaning rather than uncovering an absolute truth.

8. Actively refer to people whose contributions to science are under-recognised.
9. Help students to negotiate the discrepancy between scientific language and everyday language, especially for those students who use English as an Additional Language or have poor standard literacy skills.

(Based on Pomeroy, 1994)

The two groups who were considered in the activities were:

1. GlasWeeAsians: The activities were directed at those who had an interest in south Asia, whether because of their heritage, personal connections or out of general interest.
2. Students educated in the island communities on the west coast of Scotland, where tourism and traditional industries plays an important role in the local economy.

Plant workshop in a greenhouse

GlasWeeAsians

The GlasWeeAsian set of activities illustrated the deep, rich, historical connections between the peoples of Scotland and South Asia. Our audiences were introduced to the practicalities of plant transport, the application of plant materials, the documentation of new plants, and the people responsible and recognised during the creation of new knowledge. The activities were designed to be accessible via drop-in sessions at science festivals and in school environments, with a focus on free/cheap materials that could be recycled once the project was complete. No assumptions were made about the audience and their motivation for taking part; they were simply invited to pursue their own interest in the topic and to play (adults and children alike).

Cyanotype printing

Activities included:

- Cyanotype printing plant materials, as well as images of the first acknowledged plant explorers, from Scotland and South Asia.
- Designing Wardian cases using junk materials, adapting their builds according to the plant materials (seeds, bulbs, roots).
- “Scratch and sniff” sensory activity matching raw, unprocessed plant materials to their commercially available products using smell and sight.

The activities were primarily offered in non-formal learning spaces (such as Glasgow and St Andrews Botanic Gardens) as well as in informal learning spaces (such as Glasgow Science Centre) during British Science Week and the Glasgow Science Festival. Our audiences opted into attending the events in question but not specifically for our activities. Once in the physical space, participation was completely voluntary, save for some gentle persuasion for more reluctant, but still interested, visitors.

The GlasWeeAsian activities were well received as they enabled our audiences to apply their own knowledge and understanding to activities that they hadn't encountered before. As a result of our first event at Glasgow Science Festival, our STEM Ambassador's parent sent us dried and pressed materials from India, illuminated with the scientific plant names as well as their common English and Urdu names. This intrigued our audience and led to increased enthusiasm. These materials have been scanned and high-resolution copies are available here: https://bit.ly/DiSSI_IndianPlant for download and printing onto acetate.

We also collaborated with Dr. Saeeda Bhatti (founder and leader of STEM in the Gorbals) to create multi-language evaluation postcards for our audience to complete before and after participating in our activities; this methodology also received ethical approval from the University of Strathclyde (Ross 2023a). Upon post-delivery reflection, we realised that these cards are more suited to a workshop style delivery. Science festival environments, with limited staffing capacity, are more suited to tallying visitors or graffiti walls for evaluation purposes. All evaluation should be appropriate, pragmatic, and proportionate to the context.

"CSI: The Poorly Puffin" – Forensic science meets place-based community learning

The "CSI: The Poorly Puffin" series of short science activities is based around a crime-scene investigation linked to ecological concerns where learners are invited to explore, through a problem-solving approach, who left the (plastic) litter on the beach that was eaten by the puffins. The activities were selected to be accessible to all ages and stages, with an increasing level of complexity which allowed for differentiation by outcome and level of science knowledge and background. Each of the separate activities allowed the learner to get closer to the suspect whilst also exploring their own understanding of science and how this relates to their own place and experiences. Activities included:

- Footprint matching
- Fingerprint analysis
- Blood typing (using commercially made artificial blood)
- DNA typing.

The activities were offered in the various island communities on the west coast of Scotland, through a range of outreach workshops to teachers and community youth workers, but also to children, young people, and members of the community, both in classrooms as well as informal learning settings. The activities were offered in communities which are heavily reliant on tourism, as well as the traditional industries of fishing and small-scale farming, which are particularly affected by the challenges of global climate change and changes to ecosystems.

The "CSI: The Poorly Puffin" activities were well-received as they allowed learners to link their own individual context and sense of place to the wider, global challenges facing societies today, in terms of the environment, global climate change, the role of people and science - with clear links to the UN Global Development Goals (especially 14 – in the sea and 15 – on the land). The context of "CSI: The Poorly Puffin" allowed for clear links to be made between the activities and the lived experiences of the participants and eliciting wider discussions – for example in terms of beach debris or awareness of the importance of the protection of wildlife species for future sustainability and employment.

The activities can be easily adapted to different scenarios and contexts to make them relevant to the learners. All materials are released under Creative Commons licensing and can be downloaded here (Ross 2023b) for adaptation and reuse.

Conclusion

All members of the team enjoyed trialling activities that were targeted at groups who are under-represented in science outreach and were pleased that the activities were so well received. We found the framework set out at the start of the article a useful guide to how to approach planning inclusive activities and felt that the range of engaged participants, who ranged from toddlers through to under-graduates, indicated their wide applicability. One feature that stood out was that the activities facilitated full involvement by both target groups and others without any distinction being made between them. In that sense, we felt we achieved cultural responsiveness without any sense of ghettoization.

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Biography

Dr Jane Essex is a Senior Lecturer at the University of Strathclyde, Glasgow, UK. Her main work is in the field of Initial Teacher Education. Her research focus is inclusion in STEAM (science, technology, engineering, arts and mathematics) and her research focuses on how STEM can be made accessible to all learners. She is an active member of the Royal Society of Chemistry and was awarded their Inclusion and Diversity Award in 2019. She has recently written her first book, 'Inclusive and Accessible Secondary Science: How to Teach Science Effectively to Students with Additional or Special Needs.'

Dr Ingeborg Birnie is a senior lecturer in the School of Education at the University of Strathclyde, Glasgow where she teaches on a range of undergraduate and postgraduate programmes. She has over 20 years of experience of working with young people in different educational settings, including nursery and primary education but also as a secondary Physics and Science teachers. Most recently she has been working in the field of language and identity including a focus on exploring culture through the use of STEM activities that explore concepts around place and space.

Dr Kirsty Ross is a senior public engagement professional (PEP) with a background in academic STEM research & a strong track record for knowledge exchange working across 3 research-intensive universities in Scotland. Kirsty supports implementational, operational & strategic goals in knowledge exchange and has significant experience in researcher development and working with easily ignored audiences. She has a particular interest in making open knowledge platforms, such as Wikipedia and her sister projects, more inclusive, diverse, equitable and accessible to all.

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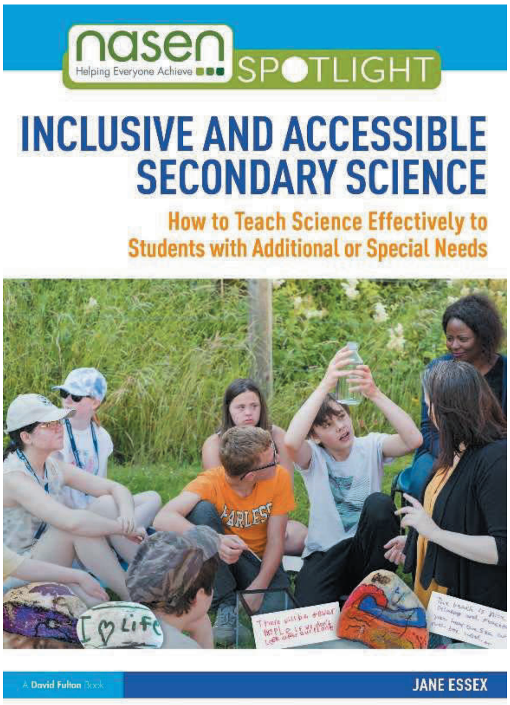

How to Teach Science Effectively to Students with Additional or Special Needs

By*Jane Essex*

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The book explores approaches to teaching and learning science with secondary aged students who have special educational needs/ additional support needs associated with learning difficulties. Although the primary focus is learners who have global learning difficulties, the material in it will also be applicable to those with specific learning difficulties too. It is intended to help specialist science teachers in mainstream settings who work with students who have learning difficulties, non-science specialists working in alternative educational settings who would like to teach science and science communicators working outside a formal school setting.

The book starts by considering the reasons that all learners should be taught science before considering the cultural and functional barriers that the standard school curriculum presents to neuro-diverse students. Practical responses to the difficulties that are inherent in the standard science curriculum. Assessment is treated as a distinct facet of the science curriculum and the ways in which it can be made to enhance learning and attainment in science is explored. How the principles set out can be applied in practice is then shown through a set of plans showing how a range of topics could be organised to optimise secure learning. The exemplar teaching schemes are for learners following a typical science curriculum for 11-13 year olds and are designed to permit access by all learners, rather than viewing inclusive science teaching as something that is targeted at a labelled group of pupils. The book closes with a section that suggests sources of further specialist support.

5E model activities in ethnically diverse classrooms

Marina Stojanovska, Katerina Rusevska, Lambe Barandovski, Slavica Tofilovska, Vladimir M. Petruševski
Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Arhimedova 5, Skopje, Macedonia
Contact email: marinam@pmf.ukim.mk

Abstract
The 5E model is an inquiry-based approach and helps students gain a full understanding of new concepts, while keeping them engaged and motivated. This model is based on constructivist learning theory, and allows students to develop new knowledge that builds on their previous concepts and scientific ideas, restructures and adds newly learned information, and at the same time develops the ability for their connection, as well as application, in everyday life. The 5E model includes five stages: engage, explore, explain, elaborate/extend, and evaluate. This paper presents a lesson plan, including several activities for the topic of gases applicable in ethnically diverse classrooms, that was developed within the project "Diversity in Science towards Social Inclusion – Non-formal Education in Science for Students' Diversity" (DiSSI), as well as guidelines for teachers regarding the procedures in each of the five phases of the 5E model. Teachers can use all or part of the suggested activities, or they can modify or add new activities according to their needs and the needs of their students.

Introduction
5E model activities as part of inquiry-based science education
Inquiry-based learning is a type of active learning that begins with posing questions, problems, or scenarios. Unlike the traditional way of teaching, which relies on the teacher presenting the facts and his/her own knowledge of the subject, this approach emphasizes the role of the student in the learning process. The teacher is the moderator in the whole process who, through focused learning, research and discussion, helps the students to build their knowledge. Although the students certainly have a responsibility in such classes, the teacher is the key figure who should enable learning. (S)he begins the research process by introducing the topic and encouraging students to discuss it. The teacher is responsible for the course of the discussion and guides the students. As far as necessary, (s)he clarifies misconceptions and provides additional information to better understand the teaching content, thus making learning relevant.

This way of teaching allows students to develop new knowledge that builds on their previous knowledge and scientific ideas, restructures and adds newly learned information, and at the same time develops the ability for their connection, as well as application in everyday life. On the other hand, it should be emphasized that learning is influenced by the students' social environment, enabling them to learn from each other and more easily transfer new knowledge to real life.

The 5E model is at its core an inquiry-based approach that helps students gain a full understanding of new concepts, while keeping them engaged, motivated and developing skills (Duran and Duran, 2004). This model is based on constructivist learning theory, which suggests that people build their knowledge from experience (Balci, Cakiroglu, and Tekkaya, 2006). By understanding and reflecting on the activities, students are able to reconcile new knowledge with previous ideas. In this way, active learning is promoted and students are placed at the center of learning and are taught to connect those understandings with other scientific phenomena or with everyday applications.

The 5E model can be used within one or more subsequent class periods. If it is applied to several classe periods, the effectiveness of the individual phases increases, and thus the possibility of in-depth learning. However, if too much time is devoted to each phase, such instruction is not as effective because students may forget what they have learned.

The 5E model includes five stages:

1) **Engage**. The first phase engages students by mentally focusing on the phenomenon, problem, or situation. The activities are designed to help students make connections between past and present experiences, recall previously learned concepts, and target essential questions and learning outcomes, while increasing their interest and curiosity.
2) **Explore**. All students have common experiences that can be used in later stages. As a result of their mental and physical involvement in these activities, students examine events, notice patterns in certain behaviors, identify and test variables, and establish cause and effect relationship.
3) **Explain**. This phase consists of two parts. First, the teacher asks the students to share their initial models and explanations from the first two phases. Second, the teacher provides additional information to support learning. Students use this information, as well as other students' ideas, to construct or revise their models and explanations.
4) **Elaborate/Extend**. Students engage in further experiences to apply, extend, or elaborate the concepts, processes, or skills they are learning to similar phenomena or problems. It is possible that some students still retain some misconceptions or insufficient understanding of the concept.
5) **Evaluate**. It is important for students to receive feedback on the quality of their explanations. This can happen informally during the previous phases, but formally the teacher can also conduct a summative evaluation at the end of this process. Students assess their understanding and abilities, and teachers assess students' individual progress toward achieving learning goals and outcomes.

The objectives of the project activities

Several activities using the 5E model as part of inquiry-based science education and an escape room as part of a game-based learning have been designed on three different topics: gases, ecology and circuits. The main focus of the activities was on the motivation of students to learn science, its importance in everyday life, and on a possible benefit both students and teachers could have in ethnically-diverse environment. These activities were developed within the project "Diversity in Science towards Social Inclusion – Non-formal Education in Science for Students‘ Diversity" (DiSSI), whose main objectives are: 1) development and implementation of innovative methods and examples of good practices for dealing with different dimensions of diversity (differences in language skills, cultural differences, socio-economic differences, ethnic differences, working with talented students); 2) promoting inclusive education;

3) supporting teachers, educators and leaders of educational institutions in dealing with diversity; 4) strengthening socio-economic diversity in learning environments, and 5) increasing students' motivation and interest in natural sciences.

To achieve these goals, the preparation of materials for good practices and further innovations in specific learning environments was planned, the purpose of which is to improve the overall educational process, as well as development of techniques for evaluating the applicability and effect of the implemented activities. This further provides support to science teachers in Macedonia, including pre-service teachers at our universities and enables an exchange of ideas and experiences with teachers related to their beliefs and thoughts about diversity in the classroom.

In this paper, the activities designed using the 5E model on the topic of gases will be presented and their application in science classes will be briefly explained.

Experimental part

5E model in social inclusion activities in ethnically-diverse classrooms

For consistency, during the development of the 5E activities we used the same template for all three areas (gases, ecology and circuits). It contains brief instructions for the teacher that should serve as a guide or reminder during the implementation of the lesson. The Table 1 summarizes the planned activities for gases lesson plan, and more detailed explanation for each of the five phases of the 5E model is given in the next section.

Table 1: 5E guide for gases activities

Grade.: ________ Subject: ______________________________ Date: ___________			
Teaching unit/ Concept:			
Objectives:	Introduction to states of matter, gases, and their properties.		
Engage Time frame: 15 minutes	**Plan:** Discussion of general terms, types of states of matter, general and special properties of gases, possible classifications of gases (by colour, flammability, smell, etc.). **Questions:** What are the main properties of gases? How are gases and liquids different? What are the differences between gases and solids?	**Materials:** Sciences textbooks (4-6th grade). Chemistry and Physics textbooks (1st and 2nd class high-school).	**Vocabulary:** Gases Hydrogen Helium Methane Air Nitrogen Ammonia Carbon dioxide Nitrogen dioxide Sulfur hexafluoride
Explore Time frame: 45 minutes	**Plan:** Students are divided into 3–5 groups to perform the activities. Depending on the age of the students and the type of lesson, some of the experiments may not be performed. In such a case, a selection of the most important contents is made.	**Materials:** A previously prepared publication or other sources of information. Different gases, from containers	**Vocabulary:** Collecting gases - under water - in an open container Explosion Implosion Obtaining CO_2 Obtaining O_2

	Questions: How many different types of triatomic molecules are you familiar with? Knowing the properties of CO, explain how you would collect this gas in a given container and why? Knowing that gases dissolve less in water as the temperature rises (unlike solids), state the advantages and disadvantages of collecting a gas (e.g., N_2O which is quite soluble in cold water) under hot water? Think about the problem beforehand (knowing that the vapour pressure of water increases with temperature).	or generated in vitro. Simple apparatus for collecting gases.	Burning
Explain Time frame: 30 minutes	**Plan:** Participants within each group exchange ideas and discuss the results of their experiment. **Questions:** The teacher, if necessary, directs the students to draw correct conclusions by pointing out existing relations (correlations) or properties of substances.	**Materials:** Wooden sticks Test tubes Lab glass tubs Paper Writing utensils Calculator Chalk Blackboard Marker pens	**Vocabulary:** Water vapour Condensation Boiling Evapouration Phase conversion Density
Elaborate/ extend Time frame: 15 minutes	**Plan:** Joint discussion of students. Indication of relations that are relevant for the frequency of the sound generated in a given gas (approximate and exact). **Questions:** What is the error made by using an approximate frequency formula instead of an exact one?	**Materials:** Precious wood recorder (plastic or wooden) Tripod Clamp Screw-holders A rubber balloon Tubes (rubber or plastic)	**Vocabulary:** Sound Ton Sound waves Frequency
Evaluate Time frame: 15 minutes	**Plan:** **Formative (questions, discussion)** Each group is given the task of presenting the results for one parameter of the flipchart paper. **Summative (quiz/project/report)**	**Materials:** Flipchart paper Markers Marker pens Self-adhesive tape	**Vocabulary:** Depending on the topic, activities ...

Teacher's Reflection:			
Next steps:			

Results and discussion

In this section, the main guidelines for teachers will be given regarding the procedures in each of the five phases of the 5E model. Teachers can use all or part of the suggested activities, or they can design different activities according to their needs and the needs of their students.

Engage

In the first phase of the 5E cycle, the teacher refers to the students' previous knowledge and discusses the basic concepts related to gases and their properties. Through this discussion, the teacher tries to introduce the students to the activities and corrects any possible misconceptions that the students have. Since the activities are related to gases, the teacher could discuss the percentage representation of gases in the air, the properties of the most important gases, the classification of gases according to density, color, smell, toxicity, reactivity, etc.

Below are some activities that can be applied in this phase.

Activity No. 1: Methods of collecting gases

The teacher has previously installed several devices for collecting gases under water (Figure 1), and then writes formulae of several gases on the board and discuss with the students which gas can be collected in which way and why. Several properties of gases can be used in this discussion, such as density, solubility, colour, etc.

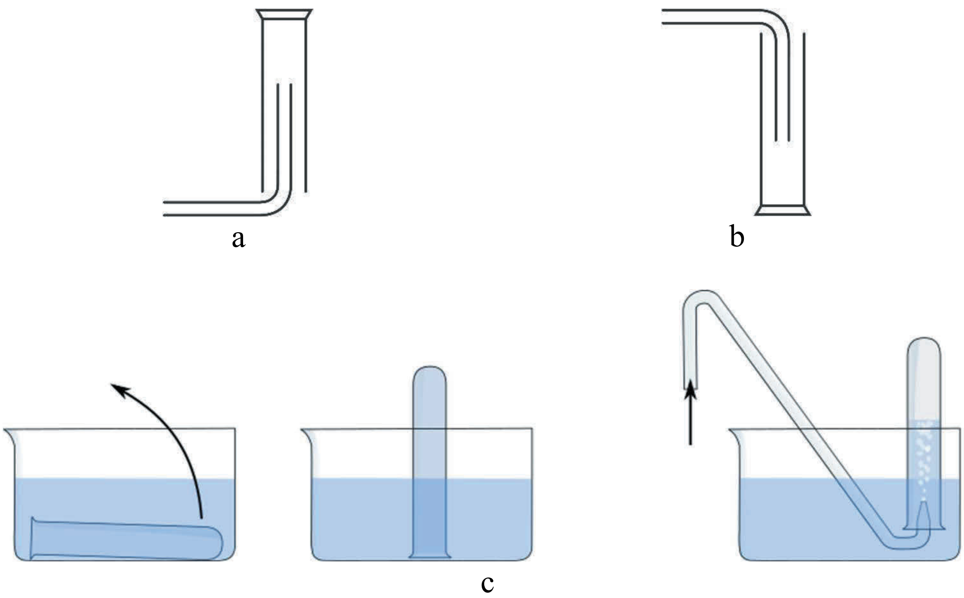

Figure 1: Different apparatus used for collecting gases: by displacing air (a and b) and by displacing water (c)

Activity No. 2: Building blocks of gases

Each group receives sketches of molecules of some gases (an example is given in Figure 2) and a list of formulae that may or may not correspond to the sketches. One of these sketches refers to a liquid (for example, water molecules). The students' task is, through group discussion, to find out what units each of the indicated substances is made of and to recognize the corpuscular diagram of the liquid.

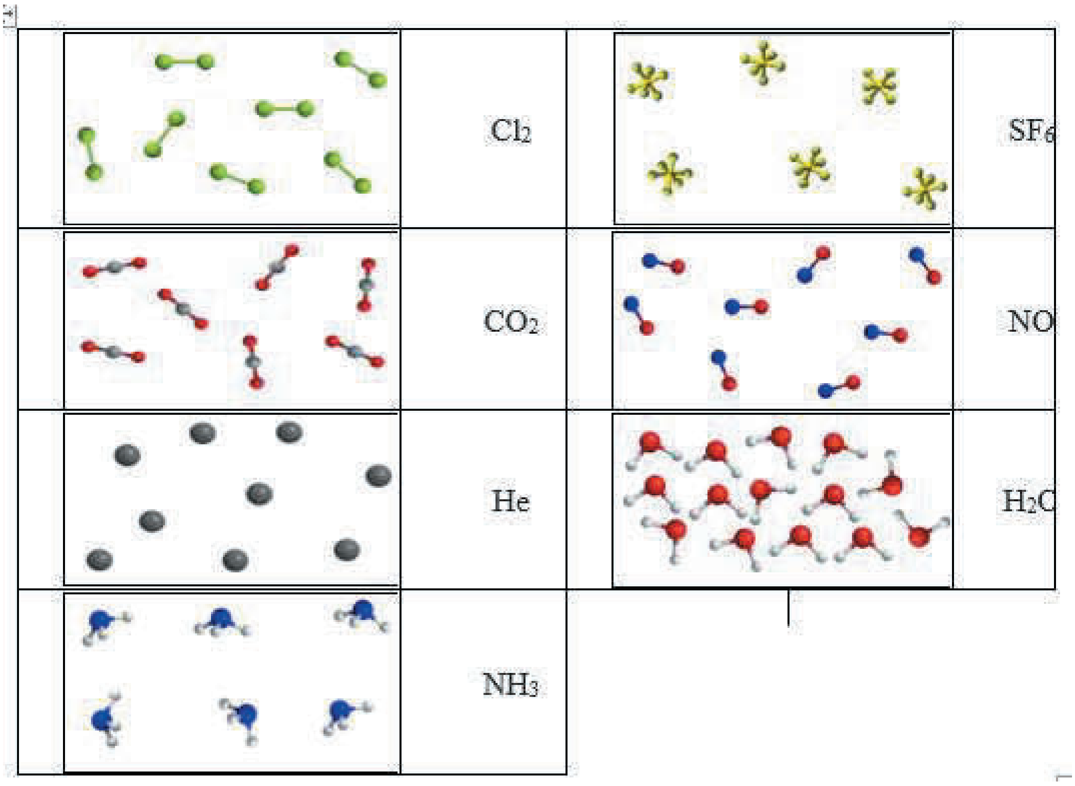

Figure 2: Schematic representation of molecules of different substances

Explore

Some of the experiments are performed by the teacher together with the students, and some by the students independently within their groups. The reason for this is the complex manipulation of some of the gases used. In the case when the teacher has to perform the experiment (in the form of a demonstration), as a rule, (s)he does not give any explanations, but only describes the procedure and performs the experiment. The discussion is conducted within the groups and the students should come to the answer independently.

The proposed activities for this phase are as follows:

- Activity No. 3: Diffusion in gases
- Activity No. 4: Experiments with SF_6 and He
- Activity No. 5: Music of hydrogen gas
- Activity No. 6: Can implosion
- Activity No. 7: Gas that does not support combustion
- Activity No. 8: Gas that supports combustion

Three of them (activities No. 4, 5 and 6) will be listed in this paper, and a full description of all experiments can be found elsewhere (Stojanovska, Rusevska, Barandovski, and Petruševski, 2022).

<u>Activity No. 4: Experiments with SF_6 and He</u>

Chemicals and equipment: balloons, glass tubs, aluminum foil, candles, glass cups, helium, sulfur hexafluoride.

Procedure:

1) An inflated balloon is placed in a glass tub filled with air. The tub is then filled with sulfur hexafluoride and the same balloon is placed back. Students are invited to push the balloon to the bottom of the tub and to explain its behaviour.
2) A handmade container made of aluminum foil is placed in the tub with SF_6. Then, using a cup or a beaker, some gas from the tub is poured into the aluminum container.

3) Three balloons are filled with helium, air and sulfur hexafluoride, respectively. They are released from the same height.
4) He is inhaled from a balloon and the explanation of the experiment continues. Then, the same procedure is repeated with SF_6. Students are invited to try the experiment (or a part of it).
5) Lighted small candles are placed on an inclined surface and SF_6 is poured from a beaker from one end of the row of candles.

Observation:

1) The balloon falls to the bottom of the air-filled tub and floats in the SF_6 tub.
2) The aluminum foil container floats above the gas in the tub, much like the balloon in the previous experiment. After pouring the gas from the cup, the container falls to the bottom of the tub.
3) The helium balloon rises up into the air, the air balloon slowly falls down, and the SF_6 balloon falls to the floor almost immediately.
4) When inhaling helium, the voice becomes thinner (higher), and with SF_6, a thicker (deeper) voice is obtained.
5) The flame from the candles goes out. This happens almost instantly with all candles.

Results and discussion:

Helium is the second lightest gas in nature, $\rho_r(He) = 4$ in contrast to $\rho_r(H_2) = 2$. The buoyancy of helium is about 93% of that of hydrogen (92.6% more precisely). Therefore, a balloon filled with helium behaves like a balloon filled with hydrogen ("flies up", if not contained).

The opposite is the case with SF_6, a gas that is 5.03 times heavier than air, ρ_r (SF_6) = 146. Therefore, a balloon filled with SF_6 falls “like a rock” compared to a balloon filled with air, which falls slowly, or the balloon filled with helium, which, again, tends to "fly up".

On inhaling helium the voice becomes thinner (higher), while inhaling SF_6 it is much thicker (deeper). This is because the vocal cords vibrate in an atmosphere of light or heavy gas, and the frequency of the sound depends on the mass of the oscillator (the air or gas in which the vocal cords vibrate):

$$\nu \sim \sqrt{\frac{1}{M_r}}$$

In other words, the frequency of sound is more than doubled when the mass increases by 5.03 times, and the voice sounds more than an octave deeper.

Both helium and SF_6 are non-flammable.

SF_6 is a fairly inert gas. It is non-toxic, non-flammable and does not support combustion, so the experiment can be carried out freely without any health hazard.

<u>Activity No. 5: Music of hydrogen gas</u>

Chemicals and equipment: two balloons (with adapters and glass taps) filled with air and hydrogen, respectively, glass bottle with a volume of 1 L, glass tube closed on one side (length 35-40 cm, width 4-5 cm), glass adapter, a once bent glass tube, precious wood recorder (plastic or wooden), tripod with socket and clamp, rubber plug with two holes, a piece (throat) of a balloon, plastic or rubber hoses.

Procedure:

The bottle is closed with a rubber stopper through which the glass tube bent at right angle and the glass adapter are inserted. The piece of rubber balloon is pulled onto the adapter, the other end of which is connected to the flute. The wide glass tube is attached to the tripod, the flute is placed in it and fastened to the wall of the tube with a piece of plastic or rubber hose. It is important that the entire flute is completely inserted into the tube.

The balloon filled with air is connected to the bent glass tube (Figure 3). The glass stopcock is opened and the frequency of the tone is noted. Then, instead of the air balloon, the hydrogen balloon is connected.

The tap is opened and the differences in the frequency of the produced tone are noted.

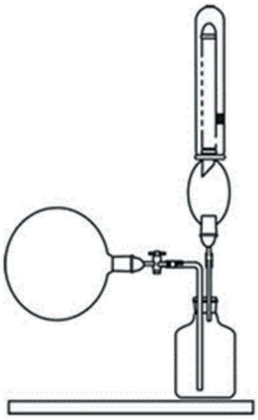

Figure 3: Apparatus for demonstration of frequency change of the tone (sound waves), when using different gases

Observation:
Air and hydrogen produce a tone with a different frequency. It is observed that the tone produced by hydrogen is much higher.

Results and discussion:
The release of air from the first balloon causes the air column in the flute to oscillate and, accordingly, a tone with a specific (constant) frequency is generated. The replacement of air with hydrogen leads to the generation of a tone with a variable (rising) frequency. The frequency of the tone changes by almost two octaves. The reason for the change in the frequency of the tone is the change in the gas mixture (it becomes richer and richer in hydrogen). As the effective mass of the oscillator (the post in the flute) decreases, the frequency increases.

Activity No. 6: Can implosion
Chemicals and equipment: can, metal tripod with an iron-wire triangle, gas heater or spirit lamp, masha, a tub, water.

Procedure:
A glass tub (basin or some other plastic container) is filled with tap water. A few mL of water are added in the can. The can is positioned on the triangle placed on a metal tripod and the water is heated to boiling. The heating should be stopped when "vapour" (more precisely, a fog) is noticed from the water above the opening of the can. In absolute silence, the can is grabbed with tongs and transferred to a tub full of water, with the opening facing down.

Observation:
When heating the can, evapouration of the water is observed. Immediately after the contact of the can with the water in the tub, a loud sound is heard. The can flattens (implodes) and fills with water (Figure 4).

Figure 4: The can after the end of the experiment

Results and discussion:
Heating the can (actually, the water in the can) is necessary to create water vapour. Therefore, the water should boil for some time. During boiling, the water vapour pressure and atmospheric pressure are equal, as the system is an open one. The vapour can be observed above the opening of the can (evapouration, or rather condensation of the vapour, can be observed). There is now water, water vapour and air in the can. As the amount of water vapour increases, it pushes the air out of the can. The more the water boils, the less air remains in the can. The vapour is, of course, in a gaseous state and, therefore, possesses all the characteristics of gases, occupies all the available space in the can, and then leaves it.
The moment when the can comes into contact with the water from the tub, a loud sound is heard, similar to an explosion. The

can, at the same moment, flattens (actually completely deforms). When the can is placed with the opening down in the tub, a significant reduction of the vapour pressure in the can occurs, due to the water vapour instantly cools and condenses (liquefies), and the liquid water occupies much smaller volume than the same amount of water vapour. The equalizing of the pressure with the external (atmospheric) pressure is impossible at first, because the opening of the can is closed by one side with the water in the tub. We can imagine that at this moment the atmospheric pressure "presses on the can" with a force of about 3000 N (equivalent to a load of about 300 kg), distributed by one kilogram on each square centimeter. Because of this, an implosion occurs (this can be understood as the reverse process of an explosion), that is, when a can collapses. The reduced pressure in the can also pulling the water from the environment, so this is the reason why the water enters the can after collapsing.

Explain
Starting from the fact that while preforming the experiments the students are only observers and are not given 'ready-made solutions', it is necessary to consider what information *can* be given to them.
Only later does the teacher give a precise explanation of the given concepts. For example, (s)he talks in detail about density (in the beginning, in the Engage phase, it was more general) without talking about the outcome of the specific experiment. The teacher can talk about the densities of H_2 and CO_2, and use He and SF_6 in the experiments (for the students to apply this concept to new examples, in new situations).

Elaborate/extend
Elaboration can be carried out in basically the same way as before: the "behaviour" of the block flute with air and with hydrogen should, for example, be explained. The idea is to draw conclusions based on the results obtained and their interpretation in a similar way as above. The role of the teacher in this part is to direct the students, enabling them to come to the answer by themselves (in whole or in part). Sooner or later the relation given bellow will be mentioned:

$$\nu \sim \sqrt{\frac{1}{M_\mathrm{r}}}$$

This relationship is approximate, but useful enough to help understand the relevant actors in the experiment. It is crucial that the heavier particles are slower in both cases, regardless of whether it is a spontaneous mixing of the gases (diffusion) or an oscillation of the column of gas in the flute. The molecular mass (a measure of the inertia) reflects the speed of movement of molecules (diffusion speed) as well as the speed of oscillation (in other words, the frequency).

Students explain the experiment/concept to the teacher and other students.
The teacher can, by asking additional questions, check whether and to what extent the concept is understood. For example, what other gas, besides helium, could be used in the flute experiment to produce a similar effect? Or, what happens if CO_2 is used instead of He?

Note: Many teachers will not be able to obtain SF_6 gas and CO_2 gas can be used as a substitute, though it is not as dramatic.

Evaluate
Several activities can be planned in this phase, such as:

- Students make a poster showing the results for a certain topic.
- A quick test to evaluate the degree of mastery of the material.

Conclusion
This article provides practical examples of the use of the 5E model in science teaching. The idea is to offer different options to current and future teachers for the realization of a lesson, in which they will activate and engage students from the

beginning of the lesson and keep their attention to the end. It has been shown that the 5E model improves the teaching processes of novice teachers and their further development, and affects their personal beliefs (Hu, Gao and Liu, 2017.) Therefore, this article represents a source of 5E activities in the field of gases that teachers can directly use or with some modifications apply in the teaching process. Several quick experiments have been designed, which are supposed to enrich the students' knowledge about gases and their properties, and to deepen their understanding of the phenomena in question. This was done as part of the DiSSI project and the initial impressions of in- and pre-service teachers are excellent. However, a more detailed analysis of the questionnaires will reveal more about their opinions regarding this approach and the way of implementing the workshops.

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Biography

Marina Stojanovska, PhD, is an associate professor in the field of chemistry education at the Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje. Her research focuses on strategies for improving chemistry teaching, alternative conceptions in chemistry, game-based learning, experiments in chemistry teaching, and others. For more than 10 years, she has been involved in the professional development of pre- and in-service chemistry teachers, national chemistry competitions, international olympiads, chemistry spectacles and other events.

Katerina Rusevska, PhD, is an associate professor in the field of mycology and biology education at the Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje. In the last 15 years, she has been involved in the professional development of pre-service biology teachers during their formal academic education, realizing theoretical *and practical lessons in the field of biology education. Also, she is part of the teams for organizing training or seminars in science (biology and mycology) for primary and secondary school teachers, students or mycology amateurs and collectors.*

Lambe Barandovski, PhD, is an associate professor in the field of nuclear physics, biophysics, electromagnetism, experimental physics and physics education at the Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje. For more than 20 years, he has been involved in the organisation and realisation of national competition in physics for primary and secondary school students. He is part of the teams for organizing workshops in science (physics) for in-service teachers, as well as training for preparing students for international olimpiades in physics (IphO) and science (IJSO).

Slavica Tofilovska, MSc, is a teaching assistant the field of mycology and biology education at the Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje. In the last 5 years, she has been involved in the professional development of pre-service biology teachers during their formal academic education, realizing practical lessons in the field of biology education, as well as in the practical lessons in mycology subjects. She is part of the teams for organization of the national competitions for in science (biology) for primary school students.

Vladimir M. Petruševski, PhD, is a retired full professor of physical chemistry and of chemistry education at the Faculty of Natural Sciences and Mathematics, Ss. Cyril and Methodius University, Skopje. His research interests comprise experiments in chemistry teaching, demonstrations, models, analogies, and animations. Fields of expertise: molecular spectroscopy (IR and Raman methods) and structural chemistry. He is involved in the organization of national chemistry competitions and international olympiads and in the organization of chemistry spectacles.

DiSSI in Action

Gifted students at the University of Ljubljana, Faculty of Education, Slovenia, doing Organic chemistry experiments (see p.19).

Know your students: some reflections on diversity, equity and inclusion (DEI)

Peter E. Childs
Peter.childs@ul.ie

Introduction

All STEM teaching, whether at school or at university, involves a diverse audience. Like the poor, diversity is always with us. I often said when I was teaching Chemistry that students are not molecules: they are all individuals and unlike molecules, don't even obey statistical laws. There are no universal student laws. This means that we must know our students. The Greek philosopher Socrates said: *"Know thyself is the beginning of wisdom."* In the diverse and inclusive STEM classroom we should rather say: *"Teacher know thy student"*. This is the basis of inclusive teaching which provides equity for a diverse student body. I am also reminded of the famous quote by George Orwell in *Animal Farm* (1944), his biting satire on communism: "All animals are equal but some animals are more equal than others." We often claim that all students are equal, that they are treated equally and have equal opportunity, but in reality, some students are more equal than others – depending on their socio-academic status, their parents and genetic make-up, their geographic location, the school choice available etc. Some students are born with silver spoons in their mouths, as we say, some with wooden spoons or no spoon. The opportunities and expectations are very different for a child depending on the country they are born in, their gender, family income, sometimes their religion, their ethnicity, their disability. Even if equality is enshrined in a country's constitution, that 'all men are created equal' may not be true in practical terms. Diversity is a given but equity and inclusion are not. I am also reminded of the poem by Thomas Gray (1751) *'Elegy written in a country churchyard'*, where one line reads: *"Some mute inglorious Milton here may lie"*, reminding us that many people are born to live and die in obscurity, their talents wasted and undeveloped. The aim of DEI is that no child should be left out; no child should miss the opportunity to develop their ability and gifts; no human capital be wasted because of lack of opportunity. This remains one of the major challenges of 21st century STEM education. Diversity has become more relevant and important in the 21st century in many countries for two main reasons:

1. The broadening of education, especially at senior secondary and tertiary levels, to include the whole age cohort, with a global aspiration for universal education.
2. Increasing diversity in populations due to economic immigration or from refugees fleeing conflict, persecution and increasingly, climate change.

In the past the main aspect of diversity to be considered was gender – male and female (single-sex or mixed schools); then teachers started thinking about diversity of ability (as in mixed-ability teaching); today ethnic diversity is a major issue in almost every country, either due to historical reasons (e.g. slavery) or long-term immigration; in addition special needs students are now often included in mainstream education; and the current wave of refugees has bought additional diversity in culture and language. Our awareness and understanding of diversity have thus greatly increased in recent years.

There are many types or flavours or dimensions of diversity, which are found at all levels of education but especially in primary and lower secondary levels, where enrolment is compulsory and universal in many countries. The least diversity is found in tertiary education (post-secondary, higher education), although the 'massification' of higher education in recent years has meant increased diversity of the student body, as intake has increased.

The main goal of diversity education is to provide equity of opportunity for every student, through ensuring that every student is fully included and not discriminated against for any reason. Equal opportunity does not mean equal outcomes, but rather that each student is enabled to develop their own potential to the greatest extent. This has always been a challenge but in the much more diverse classrooms and lecture rooms of the 21st century, across many different types of diversity, it is much more so.
Some of the main strands of diversity - demographic, experiential and cognitive - are shown in Table 1, which are blended together in each individual students.

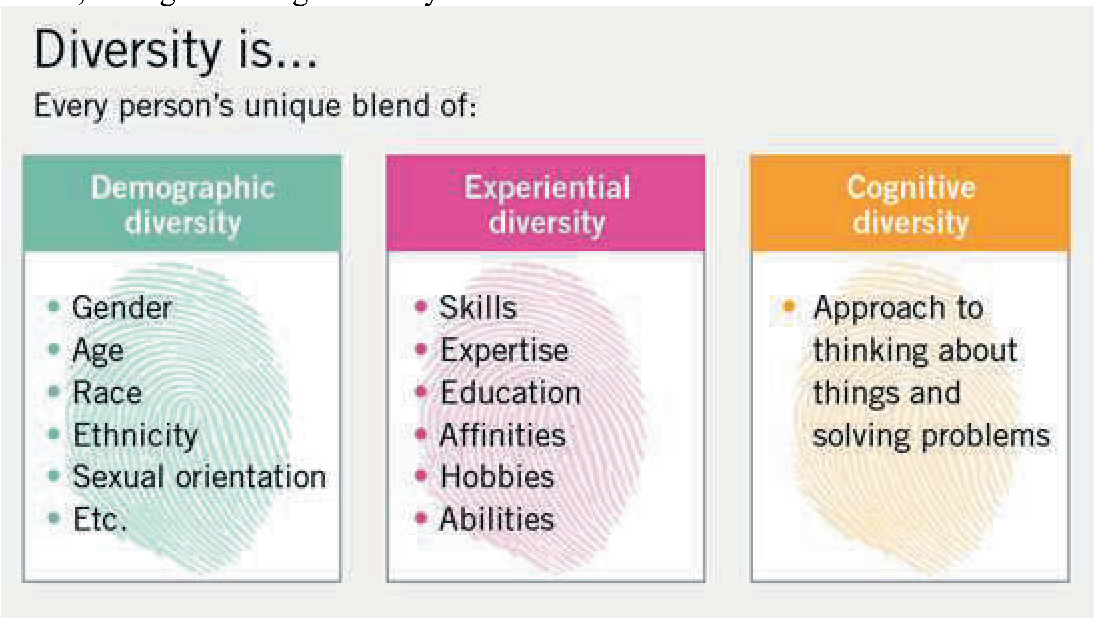

Table 1: Some strands of diversity
Think Beyond Diversity. Focus On Culture. | PPAI Media
Figure 1 shows the many dimensions of diversity that must be taken into account in the 21st century, in almost every country.

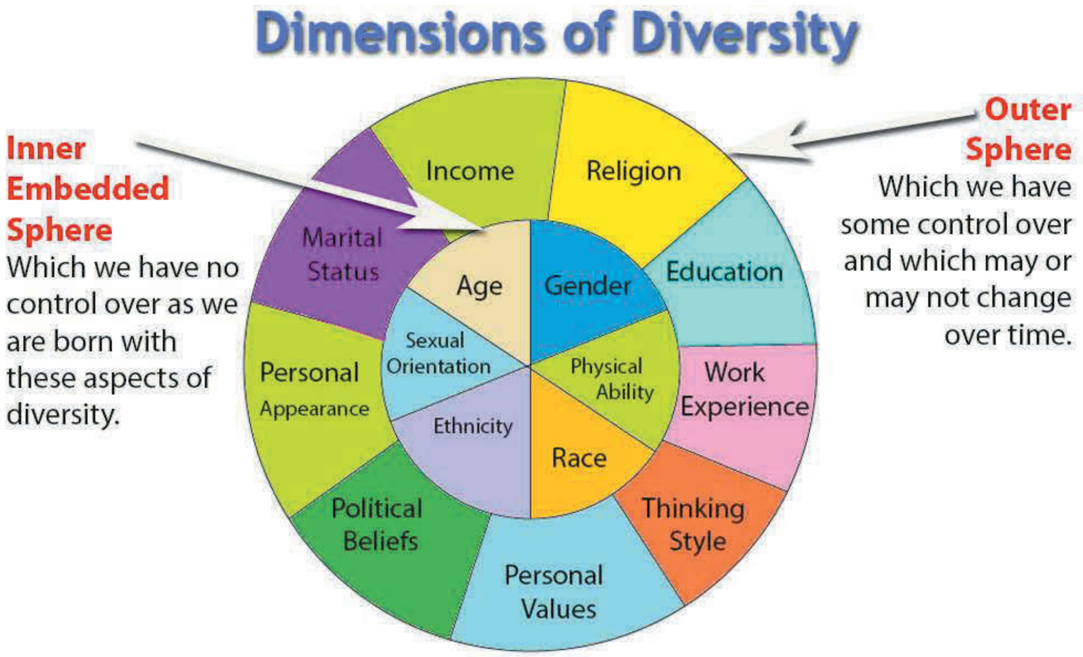

Figure 1: Dimensions of diversity
[Wheel of Diversity - 2023 Sydney University Anthology (usydanthology.com)]

The inner circle are those aspects of diversity which are inherent, determined by nature and genetics. The outer circle are those aspects which depend on nurture and experience, working with the basic genetic material.
Many of these factors overlap and affect individual students, something known as intersectionality (Figure 2).

Figure 2: The interaction of different dimensions of diversity – intersectionality
[Age, Gender and Diversity - UNHCR]

Intersectionality is the interaction between age, gender or other diversity factors, and how they affect the power of individuals or groups.
Each person has multiple characteristics, which individually or combined can lead to negative or positive outcomes in how that person is treated. For example, an undocumented refugee girl with a disability may face discrimination because of her legal status, age, gender or disability separately, or because of a combination of these factors. She will also have unique insights and strengths because of these characteristics.
[Age, Gender and Diversity - UNHCR]

Diversity can and often does lead to a lack of equity in provision and thus a failure of inclusion. Equality and equity are often confused, and Figure 3 illustrates the difference.

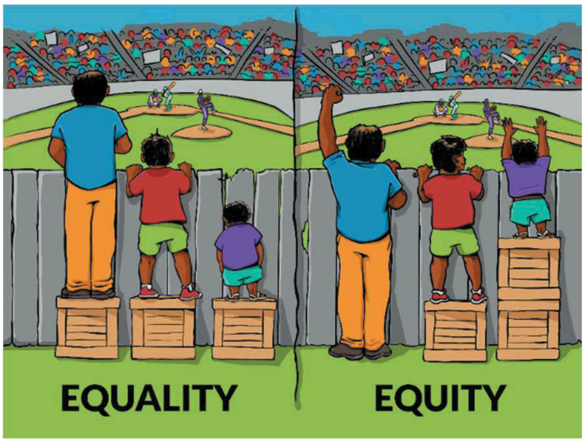

Figure 3: The difference between equality and equity
Illustrating Equality VS Equity - Interaction Institute for Social Change : Interaction Institute for Social Change

Equality means that everyone is treated equally and is given the same opportunities regardless of their background, needs or abilities; **equity** means that everyone is given the same opportunity to achieve their potential, if necessary by preferential and special treatment. For example, in a class with native and non-native speakers, extra language help would be needed for non-native speakers to provide equity of opportunity. For a student with disability equity would mean that provision was made so that the disability didn't disadvantage them, e.g. providing books in Braille for a blind student.

Targeted teaching – know your students

The first thing needed when a new group of students is encountered by a teacher is to find out as much as possible about them, so that their particular needs can be identified and assessed. Each student is an individual with their own strengths and weaknesses, their own abilities and needs, their own background and social group. The more we know about their diversity the better we can design the teaching-learning environment to provide equity of opportunity. This includes knowing their academic background and level of achievement: **'Are particular students in need of special help?'**

There is a famous quote from David Ausubel:

"The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."

This applies specifically to their previous knowledge, e.g. what topics have they covered before and to what level? But it will also apply to their reading proficiency, specific disabilities (e.g. dyslexia, dyscalculia), Maths proficiency, their age and cognitive level. The more we know about our students, the better we can teach them. **All classes are to some extent or other mixed ability.** In some schools, students are streamed by ability, either generally or in specific subjects, but at primary and junior second level classes are usually mixed ability, which also means maximum diversity.

When students change level (primary to secondary, secondary to tertiary) and move from different schools to a common school (or university), their diversity of prior educational experience may be critical. For example, at third level, in many science degrees, Chemistry is a first-year requirement and yet in Ireland around half the students taking the courses didn't do Chemistry in senior cycle. The same might be true of Maths or other sciences. The lecturer must take this diversity of prior experience into account, or there will be many failures and dropouts at the end of the course, though often students are left to sink or swim. **What do we do about this?** Several solutions have been tried to account for this specific diversity of lack of prior knowledge in specific subjects: introductory courses before the academic year starts; a foundation year to bring students up to the same level; targeted tutorials to address student deficiencies alongside the regular course; offering the subject at two levels and tailoring the level and pace to the student's prior experience.

Choosing the right pedagogy

Our choice of teaching methods will be determined by our resources, the curriculum and the diversity and background of the student body, as well as the teacher's own experience and competencies. When choosing suitable teaching methods, we must also ensure that the method chosen has a strong evidence base in their support. Teachers often teach as they were taught to teach, thus ensuring the survival of traditional methods. It is important that our pedagogy and assessment are informed by research, so that they are evidence-based (Figure 4). This is not always the case.

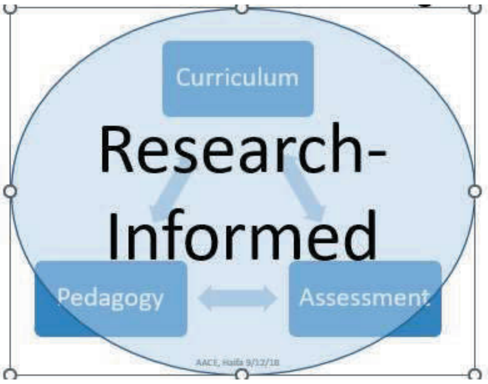

Figure 4: Our teaching must be research-informed

One of the largest and most influential review of the evidence for various teaching methods is that of John Hattie, who did a meta-analysis of published educational research to see which methods actually improved student learning, in his book *Visible Learning* (Hattie, 2012), and other publications, Figure 5. (If you haven't read this you should get a copy and study it.)

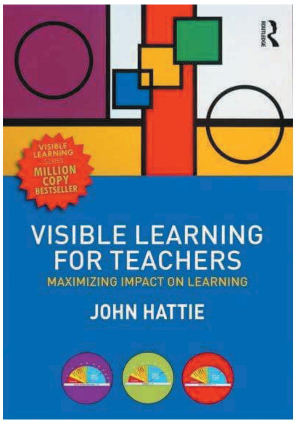

Figure 5: John Hattie's influential book *Visible Learning* (2012*)*

Hattie uses a measure called Effect Size (ES) to indicate how effective any particular teaching method is in improving student learning (Figure 6).

"Effect size tells you how meaningful the relationship between variables or the difference between groups is. It indicates the practical significance of a research outcome. A large effect size means that a research finding has practical significance, while a small effect size indicates limited practical applications." Pritha Bhandari, Scribbr, 2022

[What is Effect Size and Why Does It Matter? (Examples) (scribbr.com)]

An Effect Size of 0.4 means a year's progress for a year's teaching; 0.8 would mean 2 year's progress for a year's teaching. A negative ES means a loss of learning!

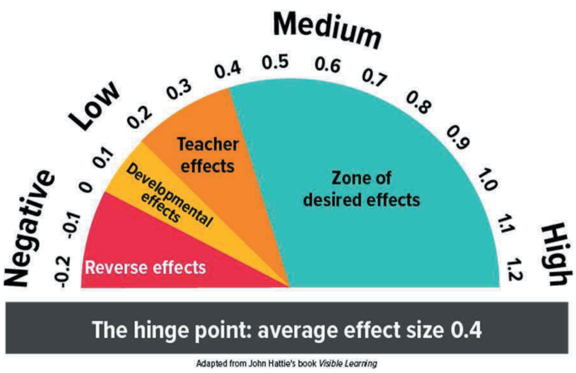

Figure 6: The scale of effect size - >0.4 means a meaningful effect on student learning

[Teacher Clarity: Part 2 in a Series on Effect Size | Learning A-Z]

Table 2 shows John Hattie's top ten teaching methods by Effect Size, though it should be noted that the 'Top Ten' changes over time as more studies are included in the analysis.

Rank	Influence	Studies	Effects	ES
1	Self-reported grades	209	305	1.44
2	Piagetian programs	51	65	1.28
3	Providing formative evaluation	30	78	.90
4	Micro teaching	402	439	.88
5	Acceleration	37	24	.88
6	Classroom behavioral	160	942	.80
7	Comprehensive interventions for learning disabled students	343	2654	.77
8	Teacher clarity	na	na	.75
9	Reciprocal teaching	38	53	.74
10	Feedback	1287	2050	.73

Table 2: John Hattie's top ten teaching/learning methods by effect size

Many popular teaching methods have a weak evidence base but are supported by tradition and anecdote. A case in point is the well-known, popular and generally accepted idea that students have different and preferred learning styles, and that teaching should be geared to each individual student's style. This common belief that students are either verbal, visual or kinaesthetic learners seems tailored to accommodate diversity. **The problem is that there is no good research evidence supporting this idea although it seems like common-sense.**

"There is no evidence that designing lessons that appeal to different learning styles accelerates student learning." William Furey
The Stubborn Myth of "Learning Styles" - Education Next

"There is no credible evidence that learning styles exist," write psychologists Cedar Riener and Daniel Willingham in a 2010 paper titled The Myth of Learning Styles. "Students may have preferences about how to learn, but no evidence suggests that catering to those preferences will lead to better learning." Patrick Carroll Friday, August 12, 2022
Learning Styles Don't Actually Exist, Studies Show - Foundation for Economic Education (fee.org)

No evidence to back idea of learning styles
The Guardian Sun 12 Mar 2017
https://www.theguardian.com/education/2017/mar/12/no-evidence-to-back-idea-of-learning-styles

John Hattie's own assessment:
*"In Visible Learning: A Synthesis of Over 800 Meta-Analyses Relating to Achievement, Hattie calculated a higher effect size of **0.41** for learning styles. The Hattie meta-analysis ranked matching learning styles to instruction **62nd out** of the 138 practices for effectiveness."*

My take-home message here is that our teaching should be evidence-based and research-informed, rather than being based on the latest fad or on anecdotal evidence, or on tradition: 'we've always done it this way'.

Great expectations

One issue with a teaching profession very different in background from their students, apart from the lack of role models (see below), is the danger of teachers have conscious or unconscious bias against certain groups and having low expectations of marginalised and disadvantaged students. It is important that teachers are conscious of any bias and deliberately ignore it and have high expectations for all their students. We want every student, regardless of diversity, to do as well as possible and to maximise their own potential. Low expectations depress student performance; high expectations elevate student performance. John Hattie's work shows that teacher estimates of student achievement has one of the highest effect sizes (1.62) of any method. Never underestimate the power of high expectations and encouragement on student performance.

Supporting diversity in the classroom

They key to addressing diversity in the STEM classroom is the teacher, and Table 3 lists 10 useful ways to support diversity.

A useful guide with lesson plans for teaching STEM through differentiation to special needs students has been produced in Ireland. (NCSE, 2008)

Table 3: 10 Ways to Support Diversity in the Classroom

[10 Ways to Teach Diversity in the Classroom – University of San Diego - Professional & Continuing Education]

1. **Examine your teaching materials:** This is a natural first step for anyone looking to focus more on teaching diversity in their classroom. While you may already be teaching some aspects of a diverse or inclusive curriculum, there are probably also subjects that will naturally be best-fits for some refreshed material.
2. **Get to know your students (and their backgrounds):** When the school year starts, consider sending home a survey to learn more about your students and their backgrounds. Always be mindful to word your questions in a thoughtful and inoffensive way. But by taking the initiative to demonstrate your interest in their culture or background, you're already doing the work of building a foundation of trust and openness about who they are and where they come from.
3. **Address inequality:** This can be one of the more difficult subjects you broach in your classroom, but it is critical that students see their teacher demonstrate an awareness of inequality. You can use examples from history, from current events or from hypothetical scenarios, but using real instances that students can relate to can help improve their comprehension and understanding.
4. **Connect with parents:** This can be done through the survey you send home or as a separate initiative, but try to engage with your students' parents too. They may have questions about how you will be teaching diversity as a subject or they may want to share their culture and background. Either way, having an open dialogue will prove beneficial for you, students and parents.
5. **Be a culturally responsive educator:** This may seem like a no-brainer, but work on actively being a culturally responsive educator. We all have unconscious bias to some degree, but by working to actively come to understand different cultural backgrounds, teachers can show their students that they are learning in an inclusive environment.
6. **Seek out PD opportunities around diversity initiatives:** This can come in the form of a workshop, conference, or even a professional development course. There are a growing number of diversity teaching professional development opportunities out there, and these can really help you start introducing these concepts into your own teaching.
7. **Be honest about and aware of your own cultural biases:** This will require some self-reflection and can be a bit uncomfortable, but to teach diversity and inclusivity you must first assess where you're coming from or where students might be coming from. By understanding your own cultural biases you can be more aware of your perspective and choices, and help other students do the same.
8. **Include classroom signs in multiple languages:** An easy and quick way to display diverse cultures in the classroom is to include bulletin boards and signage in a number of languages. You don't have to be a foreign language teacher to use this in the classroom, and a quick Google Translate will help you use the right terminology.
9. **Invite guest speakers into your classroom:** There is no better way to introduce your students to diverse people and cultures than by bringing people of diverse backgrounds into the classroom. This can be an opportunity to bring parents into class, or you can seek outside resources from perhaps a local college/university or a multicultural organization.

10. **Take field trips to cultural events in your community:** Many community organizations host events throughout the calendar that celebrate different holidays, festivals or significant dates in other cultures. These can be a great way to expose your students to the concepts they're learning in the classroom, and will give them first-hand knowledge of what they're studying.

A recent EU report on diversity and inclusion identifies five key factors in creating an inclusive STEM learning environment. (Milanovic, I. et al.,2023)
The main points to consider in achieving an inclusive STEM learning environment are:
(1) creating a personalised strategy for each student;
(2) organising teacher training programmes on how to promote inclusivity in STEM teaching;
(3) eliminating barriers, such as gender inequality or socio-economic barriers;
(4) implementing policies to support inclusivity;
and (5) involving parents and local communities.

However, there is no single prescription to fit all classrooms in all countries at all levels of education, because there is so much diversity, and this is why knowing **your** students is so vital.

Why Is Diversity in the Classroom Valuable?

Diversity in the classroom is a fact of life, and the degree and type of diversity will depend on the type and location of the school, and the country. Urban schools will often be more diverse than country schools. Countries with large immigrant or refugee populations will have more diverse student populations than other countries. Sometimes diversity is seen as a problem but it should be seen as an opportunity; sometimes diversity is seen as a disadvantage but it should be seen as an advantage. Some benefits of diversity in the classroom are listed below.

The following summarises the benefits of diversity in the classroom.
The benefits of teaching diversity are statistically proven to improve a number of student outcomes. The following are just a few results from years of research and study into the value of including diversity teachings in the classroom.

1. According to research conducted by Queens University of Charlotte, when lesson plans reflect the students and their varied backgrounds, they develop a deeper knowledge of a subject as they explore it from varying perspectives.

2. Studies have shown that having diverse classrooms helps develop tolerance and a greater sense of security when in environments with other foreign cultures present. It also helps students learn about other languages and cultures, encouraging them to be interculturally sensitive.

3. When working and learning with people from a variety of backgrounds and cultures, students gain a more comprehensive understanding of the subject matter.

4. Diversity among students in education directly impacts their performance. Studies show that students work better in a diverse environment, enabling them to concentrate and push themselves further when there are people of other backgrounds working alongside them.

5. Teaching diversity in the classroom promotes creativity, as well as better education, as those with differing viewpoints are able to collaborate to create solutions.
10 Ways to Teach Diversity in the Classroom – University of San Diego - Professional & Continuing Education

Diversity not only has positive benefits in education but also in the workplace (Figure 7). Tackling diversity properly in education thus provides a solid basis for diversity in business, industry and commerce. Many studies have shown that diversity has positive benefits in many types of business and industry. In both education and business, a major plus seems to be improvements in creativity and innovation from having people with different perspectives interacting and cross-fertilising each other.

Figure 7: The top 10 benefits of diversity in the workplace
[Top 10 Benefits of Diversity in the Workplace | TalentLyft]

Assessment and diversity

Assessment of students' achievement, whether formative or summative, is a major challenge in a diverse classroom. One size does not fit all and so teachers need to think much more carefully about how they assess students. The cartoon in Figure 8 makes this point well. An assessment designed for one type of student may not be fair to the other students. How we assess any topic will depend on the nature of diversity in our class; if we have a streamed situation, then we will assess differently a higher-ability class from a lower-ability class. Interestingly in Ireland at senior cycle, papers are set at higher and ordinary level, with an extra foundation level for Maths and Irish. The same was true at junior cycle but the latest exams have a single common level for most subjects. It is hard to see how a common paper can be fair to the complete range of student ability, especially at the two extremes: gifted and special needs.

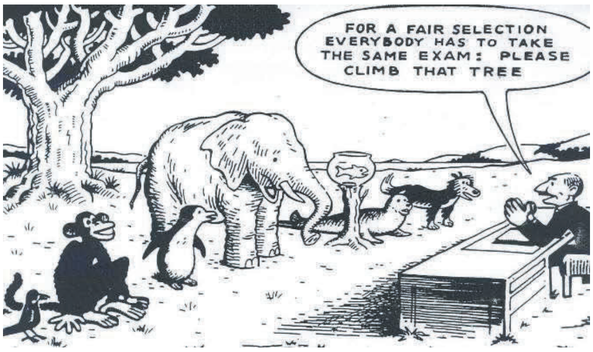

Figure 7: What makes a test fair?

'Plenty of wordy questions' for higher Maths candidates
***Irish Independent* Sat 11 Jun 2022**

Another example is the new Project Maths course in Ireland, which focuses on applications of Maths. In order to ask relevant questions, the exam questions turned out to be very wordy, so that they were as much a test of literacy and comprehension as they were of mathematical ability. Often students are strong in Maths (and numbers) and weaker in literacy (and words), and vice versa. We must make sure an assessment is fair to both groups – that's what equity means.

In the past exams were typically very wordy, designed for more academic students, with few or no diagrams, and all questions followed a similar format. Allowing for diversity in assessment means thinking about the language demand, to allow for second language learners; it means using diagrams as well as words to clarify questions; it means having different styles of questions to cover different skills, e.g. comprehension, calculation, essays, analysis, short answer, matching, true/false, multiple choice etc. The assessment should also take account of Bloom's taxonomy and a balance of higher order and lower order questions to cater for Higher Order Cognitive Skills (HOCS) and Lower Order Cognitive Skills (LOCS). These mainly account for diversity in student cognitive ability, but in a diverse classroom we should also be sensitive to cultural factors in the choice of examples, photos and diagrams. For example, questions on the history of science that only feature old, white males! This brings us to the importance of role models.

The importance of role models

Much research has shown the importance of appropriate role models for girls and marginalised groups, e.g. minority ethnic groups. Much attention has been paid in the past to the shortage of girls/women in STEM subjects, courses and careers. One key factor identified has been the lack of female role models in textbooks and in career materials. The prevailing image of the scientist is of a white, older male and this is reinforced by the examples and pictures in textbooks. If women have traditionally been written out of STEM, then so too have ethnic minorities, and people with disability. There is an increasing effort worldwide to redress this balance by have a diverse range of examples and role models, reflecting society and school populations (Figure 9).

Figure 9: This is what a scientist looks like The Harvard Gazette ['I Am A Scientist' offers students STEM role models – Harvard Gazette]

A recent paper looked at the research on role models in STEM:
"STEM fields fail to attract and retain women as well as racial and ethnic minorities in numbers proportional to their share of the population." (Gladstone and Cimpian, 2021)

Based on this review of 55 research studies, the researchers extracted four recommendations designed to ensure that STEM role models are motivating for students of all backgrounds and demographics.
The four recommendations are as follows:

- *Role models should be portrayed as being competent and successful.*
- *Role models should be portrayed as being meaningfully similar to the students.*
- *Prioritize exposure to role models who belong to groups that are traditionally underrepresented in STEM, especially in cases where only a small number of role models can be presented.*
- *Role models' success should be portrayed as attainable.*

Diversity also applies to the teaching profession, and it is important that students who might want to become teachers see role models from their social group. This is a problem in Ireland where the student body at school is becoming much more diverse, but the teaching profession is not. It is predominantly white and female!

The massification of higher education

I spent all my career teaching Chemistry to degree level, in Africa and then in Ireland and so I am interested in the issue of diversity at university level. Higher education has gone from being a minority pursuit for the elite, initially for a socioeconomic elite and then a meritocratic elite, to a mass enterprise. This has been called the massification of higher education (HE). This means not only a massive increase in numbers, and in the percentage of school leavers going on to some form of higher education (>50% in Ireland), but also an increase in cognitive diversity, as well as the other types of diversity found in modern society. In HE there is considerable gender variation in the uptake of STEM subjects by subject, as there is at senior secondary levels. Thus girls favour Biology, Chemistry has a slight majority of girls and Physics and Engineering a majority of boys. Maths, Physics and Engineering have low numbers of women in HE and thus in these STEM careers.

Teaching in HE becomes a very different experience if the cohort has a wide range of cognitive ability, often measured by IQ or similar tests. These have been criticised for being culturally biased and narrowly-focused on one type of intelligence. Whether boys and girls, men and women have the same cognitive ability has long been a controversial question.

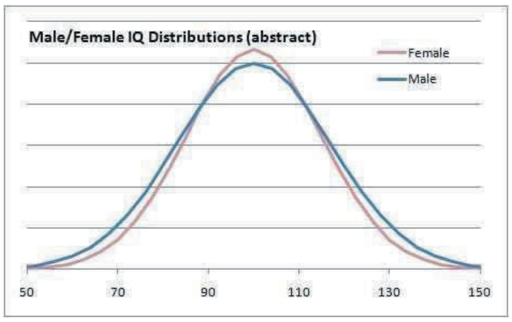

Figure 9: Bell curve of cognitive ability for females and males

Figure 9 shows the typical Bell curve of cognitive ability for males and females and Figure 10 showing a typical general IQ curve.

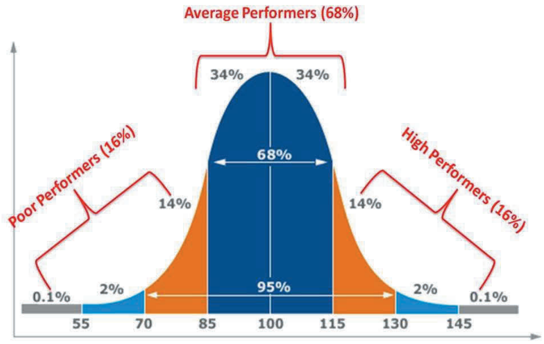

Figure 10: The Bell curve and academic performance

[Bell curve assessment — trendy practice that has fallen out of favor | by Supriya Nigam | Medium]

There are small differences at the two extremes between males and females but generally they have similar spread of cognitive ability. HE in the past was mostly university education and was restricted to the top 10% or less of the population and cognitive ability curve. These were in the main the high performers in Figure 10 at the top end of the curve. At the very top we find the gifted students. As numbers have increased, more and more of the ability curve has been included and this means a much more academically- diverse audience. In many countries the top half of the curve now goes on to HE of one sort or another. One might expect problems in teaching such a diverse population, where the 'tail' is actually the majority, and this would be expected to result in a decrease in the number getting good degrees (in the Irish and English system, firsts and 2.1 degrees) or higher grades. What we have seen in both the UK and Ireland, both at senior secondary and university level, is an **increase** in the percentages getting the highest grades and best degrees. This has been termed *grade inflation* and has been ascribed to a dumbing down of the educational experience and assessment to allow for changes in the student body. The reality is that lecturers are facing larger classes with a large, weaker tail and if they set the exams of the same standard that they used for a less diverse student body, then a large number will fail. There is then pressure from the administration to lower standards and reduce failure rates, and this leads inevitably to higher grades. It reminds me of Alice in Wonderland and the cry after the race, when the Dodo said *"Everybody has won and all must have prizes"*. Grade inflation at school affects the quality of intake into HE, as less discrimination is possible; in HE it affects the quality of graduates and their fitness for the workplace, as many employers have observed. Dumbing down should **not** be the response to wider cognitive diversity, but rather more effort to raising up students, who for one reason or another, perform poorly, but still retaining high standards. In training brain surgeons or doctors or engineers or chemists or linguists, we want their qualification to mean something and be a measure of their competence.

Poor student performance may not be due to intrinsic ability (which is a reality) but may also be due to poor language skills or weaknesses in mathematics, as language proficiency and mathematics are the two pillars of STEM subjects. Remedial or foundation courses can be offered to make up deficits from school, and additional tutorials can be targeted at at-risk students. The Irish HE system used to be a two-tier system of universities providing mainly 4-year bachelor degrees and Institutes of Technology (ITs) were originally set up to offer 2-year Certificates and an additional 1-year to Diplomas, for less academic students with a vocational bent. This has largely disappeared as the ITs started offering 4-year honours degrees in addition to Certificates and Diplomas, and now have been rebadged as Technological Universities, offering the whole range of courses as the traditional universities. All HE institutions now offer the same portfolio of courses at the different levels (Figure 11) and the diversity of provision, to allow for the diversity of student population, has largely been lost. One wonders whether the diversity of student ability is catered for by uniformity of course provision.

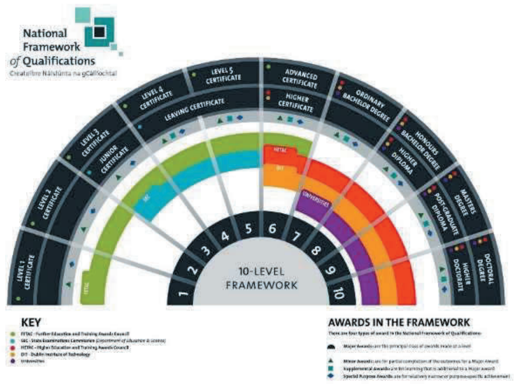

Figure 11: National Framework of Qualifications
[National Framework of Qualifications | Union of Students in Ireland (usi.ie)]

Problems and challenges with DEI

Diversity, equity and inclusion have become major issues in education in general and STEM education in particular, but this is not without its challenges and problems.
Some of the problems of implementing DEI in the STEM classroom include:

- Lack of extra resources in school to deal with diversity issues, e.g. special needs assistants.
- Lack of specialised equipment to enable disabled students to participate in e.g. lab work.
- Lack of parental support, e.g. in language or Maths.
- Disparity in socioeconomic background disadvantaging poorer students e.g. lack of internet or computers or books at home.
- Confusion of equity with equality so that students in need don't get extra help.
- Danger of dumbing down so that everyone gets good grades and

individual differences are concealed.

- Unconscious or conscious bias by the teacher against specific students or groups. E,g, girls are no good at Maths.
- Using a 'one size fits all' approach to pedagogy or the curriculum, without recognising students' different abilities and aspirations. E.g. not providing more academic and more vocational options to suit the individual student.
- Danger of stereotyping groups rather than dealing with individuals.

A recent SWOT analysis of cultural diversity identified some of the positive and negative aspects.

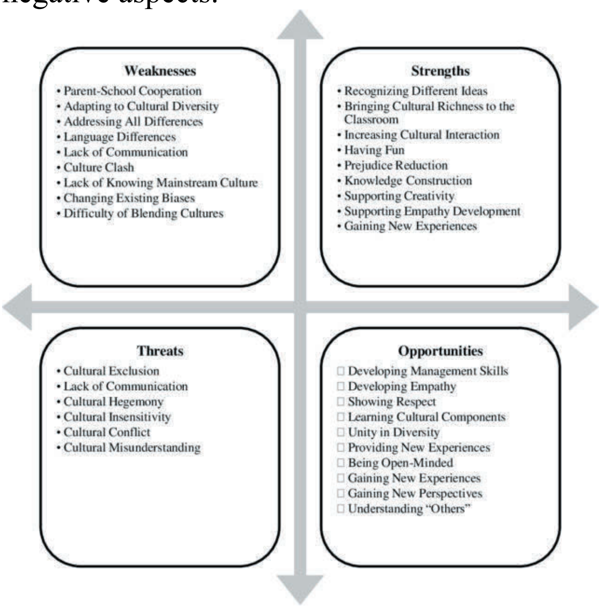

Figure 12: A SWOT analysis of cultural diversity (Erbas, 2022)

Conclusion

Our overall aim as STEM educators should be that every student we encounter, whatever their age or level of study, should have the opportunity and adequate resources to develop his or her potential to the full, and be equipped to play a full part in society. This recognises diversity, as students are not the same, and aims to include all students in the learning community so that everyone feels they belong, by providing equity of opportunity and resources without requiring equality of outcomes. This recognises differences in ability and aspiration among students and tries to ensure that every student achieves their potential and is equipped for lifelong learning. To rephrase Ausubel: ***'Find out where your students are coming from (social and academic background, culture, language and Maths proficiency, etc.), and teach accordingly.'*** The STEM teacher must know their students individually and the most important attitude they can bring to the diverse classroom is high expectations for all their students.

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□

Chemists you should know: #12

William Champion 26/April/1710- 22/May/1789

Adrian J. Ryder Email tutorajr@gmail.com

Of the 118 elements now in the Periodic Table only 94 occur naturally on Earth: 91 of the 118 are metals, 7 are metalloids and 20 are non-metals. Of the 94 elements found naturally, 18 are non-metals and 7 are metalloids leaving 69 metals which are found naturally. Of these 6 exist in extremely trace quantities, these being technetium, promethium, astatine, francium, neptunium and plutonium. In 1700, however, only 8 of the metallic elements were known. These were copper, silver, gold, iron, tin, mercury, lead and zinc, a metal which was discovered in the East (probably in India) and which was imported into the West during the 17th century in small, expensive amounts. The credit for the isolation and production of zinc from resources in the West is given to William Champion of Bristol, who is the subject of this essay. However, the credit for the formal recognition of zinc as a new metal was not made until 1746 by the German Andreas Sigismund Marggraf (1709-1782). There is no known portrait of William Champion.

Below are two gemstones of the rare mineral sphalerite, virtually pure zinc oxide; the mixed rock form is the raw ore for the extraction of zinc. This is mined at Navan by Tara Mines.

3.09 carat Sphalerite (ZnO) low iron Substitution. (ZnO to FeO)
(Photos Evan Ryder)

9.4 carat Spalerite (ZnO) high iron substitution (ZnO to FeO). The greater the iron content the darker the stone.

A comprehensive family tree for the Champions is to be found online, and the reference given at the end of this essay. The tree begins with a William (b.1595), the great-great grandfather of the subject of this essay. The immediate line to our William shows father, grand-father and great-grand-father all named Nehemiah, distinguishable by the Roman numerals I, II and III after their names. Nehemiah I (b.1614) was one of the earliest members of the Quakers, a Christian breakaway sect from the Established Church (Anglican), which came into existence during the years of the English civil war (1642-1651). His offspring were to be staunch Quakers thereafter. Nehemiah II (1649-1722) had five children of whom Nehemiah III (1678 -1747) was the youngest. His older brother, also named Nehemiah was born in 1666 but died in 1678.

Nehemiah III married Susanna Truman on the 3rd August 1703 and the couple were to have four children: John (1705-1794), Ann

(b. 1707), Nehemiah IV (1709-1982) and the subject of this essay William (1710 - 1789). Nehemiah III was to remarry (in 1742) a widow, Martha Vandewall, the sister of Thomas Goldney III. Nehemiah III was a leading partner in the Bristol Brass Wire Company, based at Baptists Mills, a brass works in Bristol, which he and other Quakers had established in 1702. Prior to this he was a tobacconist, as had been his father before him. This prominent Bristol family has been honoured by having a square named after them – Champion Square in Bristol.

Nothing is known about William's education but it is likely he was introduced to the workings of the brass works at an early age, learning the various processes at first-hand from the skilled workers there. At the age of eighteen he went to Holland, where he spent time in various brass works there, furthering his knowledge of the processes. It was during this time that he came across the Indian method for the extraction of zinc from its ore.

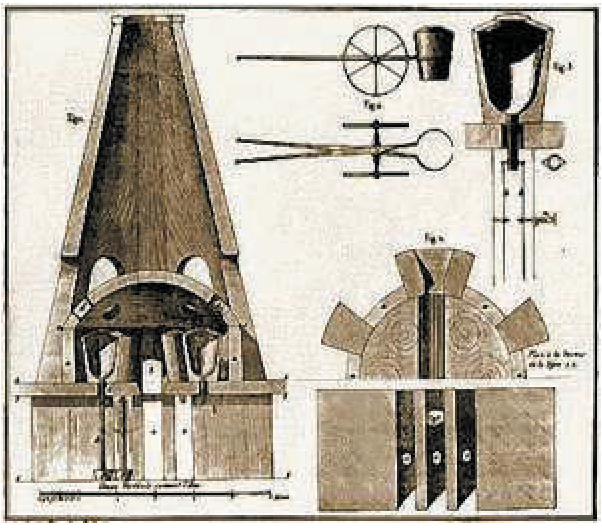
Returning to Bristol in 1830 he spent the next six years experimenting to replicate the zinc extraction process. He patented his findings in 1738. Meantime the Bristol Brass Company financed the establishment of works at the Old Market, which were in full production by 1742 using a giant kiln consisting of six separate crucibles, which fed the vaporised zinc through an iron tube into cold water, from which the condensed zinc was taken and moulded. Each charge of the crucibles, consisting of calamine (impure zinc carbonate) mixed with charcoal, produced some 880 lb (400 kg) of zinc and some 204 t (200 tons) were produced each year. This was the first European production of zinc, which in 3% to 45% amounts is alloyed with copper to form the different types of brass. Initially calamine was imported from Kelmis, a small Belgian town 42 km from Liège, but later calamine was mined in the Mendip Hills to the south of Bristol and Bath. William was able to undercut the price of imported zinc from the Orient considerably, to the chagrin of the Bristol importers. The price of zinc fell from £260 per ton prior to William's intervention, to just £48 a ton by 1750.

The works produced large amounts of polluting smoke, which led to the local residents demanding that the works be stopped. This local dissent, the animosity of the local zinc importers and the fall in the price of zinc, led William to look elsewhere to locate his works. William's father had married into the family of Thomas Goldney III in 1742 and with the backing of this family, William left the Bristol Brass Company and set up new works at Warmley, a village between Bristol and Bath. The shares in the new Company were divided eight ways and the partners contributed over £1000 each. (The equivalent today, 2023, of over £223,000.) Among the partners were Sampson Lloyd, a Quaker iron-founder of Birmingham who had married William's sister Rachel; Thomas Goldney; and Thomas Crosby, two other Quakers. Because some of the partners were also members of The Bristol Brass Co., it was to be the cause of ill feeling, which later developed into acrimony.

The original investment by the partners was not sufficient to complete the new works and unforeseen costs of cast iron equipment meant the shortfall required the partners to invest more capital, which they did by giving loans on which interest was to be paid.

William had houses built for his workers, many of whom came from Holland, close by the works. As well as these he built a fine Dutch-style house close to the works with ornate grottos and gardens for the use of his guests, a 13-acre artificial lake to provide water for the works, with a windmill to assist with water circulation, and what was one of the largest ice-houses in the country.

Workers were paid 50 d a week for smelters, while some of the more skilled were paid 75 – 90 d a week. Children as young as nine were employed as pin makers earning a mere 6 d a week. (These figures correspond to approximately £112, £167 to £192.5 and £5.60 respectively.)



A diagram showing the interior of William Champion's zinc-smelting furnace
Bristol City Council : Museum Collections

In 1766, Dr Richard Watson described William Champion's zinc-smelting process: *'In a circular kind of oven, like a glass-house furnace, there were placed six pots about four feet each in height... into the bottom of each pot was inserted an iron tube, which passed through the floor of the furnace into a vessel of water. The pots were filled with a mixture of calamine and charcoal, and the mouth of each was then close stopped with clay. The fire being properly applied, the metallic vapour of the calamine issued through an iron tube, there being no other place through which it could escape, and the air being excluded, it did not take fire, but was condensed in small particles in water...'*
Bristol City Council : Museum Collections

A dark side to the Champion family works is its connection to slavery. By the end of the 1730's some 8,000 of the 20,000 enslaved Africans a year were transported on Bristol ships to the British Caribbean and North America. The same ships carried to Bristol-made goods to Africa and on to the Caribbean, where they loaded sugar, tobacco, coffee, cotton, spices etc. destined for the English markets. The Warmley Works were to send much of their production on board these ships, including their speciality, the 'Guinea' cooking pot, which found wide-spread use in the preparation of the slaves' meals. Bristol merchants made a lucrative income as a matter of course by investing in the ventures of these slave-ships. Even as late as 1789, the Bristol slave trade and associated goods comprised some 80% of Bristol's trade abroad. Overall Bristol ships carried over 500,000 enslaved Africans to the Americas. A sad note is that due to overcrowding and the harsh conditions aboard these ships, about half the human cargo did not survive the journey across the Atlantic and were dumped without ceremony into the sea. The ships' crews were also susceptible to harm from poor food leading to widespread scurvy and infection from the humid pestilence of the west African river mouth. The eighteenth-century Annals of Bristol reported:
"The river (African) of late has been very fatal. There have been three captains belonging to Bristol died within these few months, besides a number of officers and sailors". The ships lay an enormous time on the pestiferous coast, for the writer adds:- "I do not expect that our stay here will exceed eight months". In a subsequent report of a committee of the House of Commons it is incidentally asserted that about 1766-7 a Bristol slaving ship was two years upon her voyage to the West Indies, having had to lie off the African coast until slaves were brought down from the interior."

A study of the ships prepared in Bristol for the slave trade during 1758 shows eighteen ships in all. Of these six were taken by the French, (the Seven Year's war 1756-1763 being in progress), one disappeared without trace and of the remaining eleven, only one reached its destination without loss of lives of the crew Two of the ships lost 24 of 40 crew-members and 26 of 70 crew-members respectively. The slave trade was a lucrative but risky business and one in which almost everyone in that time took part in.

The site of William Champion's Brass and Zinc works, Warmley
Bristol City Council : Museum Collections

Built in 1750 for William Champion and is a Grade II listed building. Warmley House is now a care home for the elderly and its partly surviving grounds make use of existing features from earlier industrial works. Warmley is about five miles from Bristol and ten from Bath in the south-east of England.

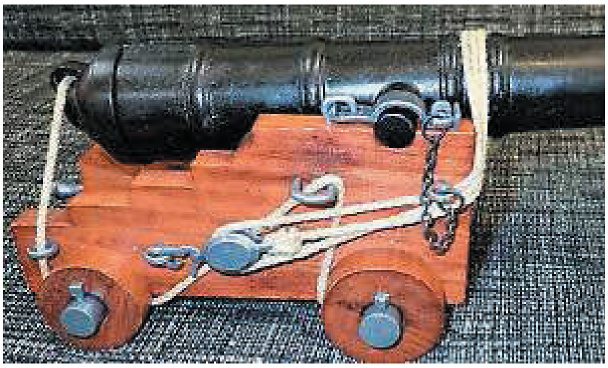
Warmley House Care Home

Over the next few years the Warmley works became the biggest metals processing plant in the world, producing not only zinc but also copper, brass and other metals. A contemporary article shows the Works to have: *"15 copper furnaces, 12 brass furnaces; 4 spelter or zinc furnaces; a bater [battery] mill, or small mill for kettles; rolling mills for making plates; rolling and cutting mills for wire; and a wire mill both of thick and fine drawn kinds."*

Following the death of his father in 1747, William was joined in the business by his brother Nehemiah IV and sister Rachel as shareholders. In spite of the expiration of his original patent and failure to have it extended, the Warmley works expanded to include new furnaces in Kingswood, a forge at Kelston and a Battery Mill at Bitton. By 1768 the group had some 2,000 employees. Now a rich man, William was involved in a number of misguided investments. Among them were the development of a new dock on the eastern bank of the river Avon and a floating harbour in Bristol, both of which were to greatly over-run the original estimates, which both depleted his capital and forced him to sell out in 1770.

"During the year 1765, Mr. William Champion, whose scheme for a floating harbour has been recorded, constructed a large dock for repairing ships on the bank of the Avon, near Rownham. The adventure proved unfortunate, and the place, commonly known as the Great Dock, was purchased by the Merchants' Society in 1770 for £1,420. The premises, with "the little dock" adjoining, were advertised to be let in May, 1772. Subsequently, a plan for deepening the large dock, to enable it to accommodate large vessels, was approved and carried out by the Society, and Parliamentary powers were obtained in 1776 to enlarge the dock and erect warehouses. The additional outlay is stated in the Bush MSS. to have been £ 1,500. A local pamphlet published in 1790 stated that "the dock is capable of containing 36 of the largest" (Annals of Bristol in the eighteenth century)

Another misguided financial venture was his investment as part owner of the slaver "Nancy", which fitted out in Bristol during 1758. The others involved in the venture were James Rumsey and Co., James Gotley and Francis Smith. The Nancy was a ship of one hundred tons with a crew of thirty. She was armed with twelve carriage guns and four swivel guns on the bridge as a deterrent not only against privateers but also against mutiny by the crew or revolt by the slaves. The Nancy set sail in August 1758 but was one of the ships taken by the French in January 1760 ,causing the owners a total loss of their investment.



A carriage gun of the era.

The investment losses and the failure to gain the necessary finance for the expansion of the works saw William trying to withdraw part of his invested capital from the company without permission, which led to his instant removal by the directors in 1766. Now deprived of an income, William fell into debt and was declared bankrupt in 1769. This same year saw the Warmley Works being auctioned off, with the Bristol Brass Company being the successful bidders. All the investors in the Warmley Works lost their investment in the company with one, Norborne Berkeley, 4th Baron Botetourt, being financially ruined but saved by George III by being made Royal Governor of the Colony of Virginia in 1768. He was to die, unmarried, there on October 15th 1770. All the Warmley processes were shut down with the exception of the pin-making section, which continued into the 1830's. On 22 May 1789, William Champion died at the age of 84 at Somerset Street, Bristol.

In 1741 William married Ann Bridges (parents George and Elizabeth) and the couple had five children: Elizabeth (30/4/1742), William (19/10/1743), Love (7/4/1745), John (26/3/1746) and Ann (24/6/1748). Ann was born in 1721 and died shortly after the birth of her fifth child, also named Ann, in 1748. Little is known about William's children apart from a note stating that John followed in the steps of his father as a metal manufacturer in Bristol and Ann married a Captain James Williams in 1770 with the couple having eight children.

Bristol became known as a centre for zinc smelting and there was a large zinc smelter at Avonmouth from 1967 to 2003.
National Smelting Company - Wikipedia

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Chemlingo: Alchemical leftovers

Peter E. Childs

Very often we use words in chemistry (or in everyday language) without understanding their real meaning or their origins. Sometimes these words are linguistic fossils, long dead and buried away from their original context, but still surviving in the language. For example, it is not uncommon to find someone referring to the '*quintessence*' of something e.g. *"The juice of the grape is the liquid quintessence of concentrated sunbeams."* Thomas Love Peacock

Quintessence is an ancient alchemical term and literally meant the fifth essence (or element). In addition to the four elements – air, earth, fire and water – the quintessence (the fifth element) was the thing that was believed to hold the heavenly bodies together. It was vital stuff somewhat akin to today's dark matter. This is where the title of the SF film *"The Fifth Element"* comes from. It is also the new buzzword in Physics to refer to a quantum field which holds everything together.

Another term in common use is the phrase '*hermetically sealed'* to refer to something sealed under vacuum. How would you guess the meaning from the name if you didn't already know it? Vacuum-sealed is obvious but the word 'hermetic' is almost unknown outside this usage and is another alchemical term. However, it is still used metaphorically as in this example.
"The Unconvincibles are the people who are not amenable to reason of any sort. Their minds are not only closed, but bolted and hermetically sealed. In most cases, their beliefs congealed at an early age; by the time they left their teens, they were encased in a rigid framework of thought and feeling, which no evidence or argument can penetrate."
Sydney J. Harris

The *elixir* or *elixir of life* was a magical substance which the alchemists believed could turn lead into gold and prolong life. It came to be used as a term for a magic medicine that would cure all ills and it is now used metaphorically for something that will transform your life. Work, love, music, coffee and tea have all been described as the elixir of life.
"Work is the true elixir of life. The busiest man is the happiest man." Theodore Martin

Fulminate is used of an explosive substance, like fulminate of mercury, used as a detonator. It comes from the word to be struck by lightning (Latin *fulmen* = lightning) and was applied to explosions and also to a thundering denunciation of someone. The word is in common usage today to describe someone who criticises angrily. Two examples are given below.
"In the 18th century advice columnists in papers such as the Spectator fulminated against arranged marriages." The Economist Dec. 26th 2017

"I confess that I do not see what good it does to fulminate against the English tyranny while the Roman tyranny occupies the palace of the soul." James Joyce

These are a few examples of alchemical fossils in our everyday language. See if you can find any more.

□

The sulfur story: devil's gold or essential element?2. The many forms of sulfur

In the last issue we looked at the sources and extraction of sulfur, one of the most important elements in the Periodic Table. It is familiar in the school laboratory as a yellow powder, flowers of sulfur. But like many other elements, sulfur exists in different forms or allotropes. In this article we will look at the structure of sulphur and its common allotropes. Sulfur forms the most solid allotropes of any elements, over 30!

Allotropes of sulfur - Wikipedia

a) Flowers of sulfur or α-sulfur, S_8

Flowers of sulfur (British spelling flowers of sulphur) is a very fine, bright yellow sulfur powder that is produced by sublimation and deposition. It is known as flores sulphuris by apothecaries and in older scientific works. Natural sulfur was also known as brimstone, hence the alternative name flowers of brimstone.

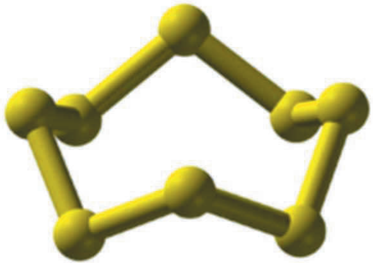
Flowers of sulfur - Wikipedia

Flowers of sulfur

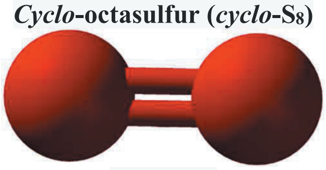
This is the most common form, found as a powder or sometimes as solid lumps, melting at 114ºC.

Sulfur is a non-metal and unlike oxygen, favours the formation of single bonds rather than double bonds. Thus sulfur is found as S_8 molecules, and due to large molecular mass is a solid at room temperature. Oxygen is found as dioxygen molecules, O_2, which is a gas.

The small oxygen allows for good overlap of p orbitals to form a strong double bond ($\sigma + \pi$); the larger sulfur atom forms weak π bonds and thus favours σ single bonding. Thus oxygen is a diatomic gas, O_2, and sulfur is a solid, S_8.



***Cyclo*-octasulfur (*cyclo*-S_8)**



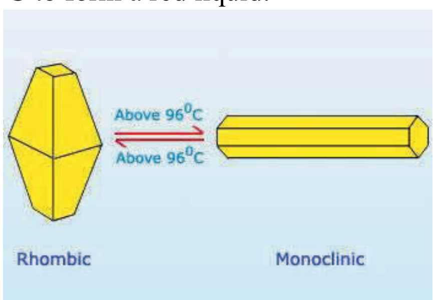
Dioxygen

α-sulfur is also sold in the form of roll sulphur, solid cylinders of crystallised sulfur, but this is not as convenient in the laboratory as powdered sulfur.

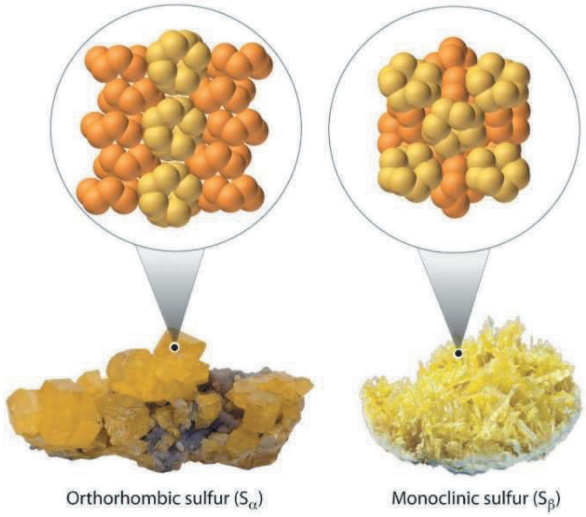
Roll sulfur

b) β-sulfur , monoclinic sulfur, S_8

α-sulfur forms rhombic crystals but when heated about 95.3ºC it transforms into monoclinic crystals of **β-sulfur.** This form melts at 120 **ºC** to form a red liquid.



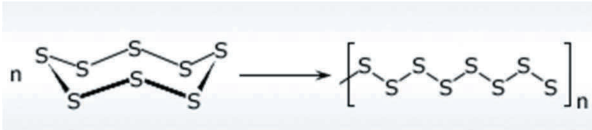
If rhombic sulfur is heated in a test-tube to around 100 ºC and then quickly quenched into cold water it forms monoclinic crystals of **β-sulfur.** They both contain S_8 molecules but these are arranged differently in the solid, giving rise to crystals of different shape.



Comparison of α-sulfur and β-sulfur structures and crystals
Chemistry of Sulfur (Z=16) - Chemistry LibreTexts

c) Plastic sulfur

When just melted sulfur is pale yellow and contains S_8 molecules. As it is heated further the colour darkens as the S_8 molecules start to break up and form chains and rings of different sizes. It darkens in colour and starts to form long polymeric chains, viscosity increases and then beyond 180 **ºC** the chains start to break up and viscosity falls. The liquid boils at 445 ºC containing mainly S_8 molecules. If the liquid sulfur at around 160-180 ºC is poured into cold water, a rubbery, dark coloured plastic sulfur is produced. On standing this slowly converts to yellow rhombic **α-sulfur**. This can be nicely illustrated using molecular models and is a common classroom demonstration (but do it in a fume cupboard).



See this YouTube video which shows the formation of these allotropes of sulfur.
(483) Part 2 Experiments with Sulphur - YouTube

The other allotropes of sulfur are less common and contain various-sized rings. In the vapour the S_8 rings break up forming smaller rings, amongst others, S_3 and S_2 molecules analogous to O_3 and O_2, with similar bonding. Sulfur burns with a characteristic blue flame, which is due to emission from the S_2 molecules at high temperatures.

In the next article: H_2SO_4, sulfuric acid – a measure of economic prosperity

□

Diary

2023

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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)

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Hon. Editor
E-mail: peter.childs@ul.ie
Communications in e-mail are preferred.
You can also send contributions to one of the assistant editors:
Marie Walsh
marie.walsh@lit,ie
Maria Sheehan (web editor)
mariasheehan400@gmail.com
Sarah Hayes sarah.hayes@ul.ie
Anne O'Dwyer
anne.odwyer@mic.ul.ie

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Vanadium flow batteries: a new form of energy storage

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