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Successful Experiences in Chemistry Teaching and Learning: A Review of Some Suggestions for Good Practice

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Abstract
In the context of lifelong learning of Chemistry and allied subjects, the issues with student motivation and the importance of adequate teacher education and training have been discussed previously. Motivating students and providing relevant learning experiences require a continuum of effort from teachers. Technology-enhanced learning has become a sine qua non in the modern classroom situation. Recognition of the different learning needs and styles of individuals – who can no longer be classified as 'traditional' learners - is important. Multicultural classrooms present linguistic challenges that go beyond the learning of the new vocabulary of Chemistry for traditional students. Internationally research groups are addressing issues with Chemistry education, and many projects have sought to narrow the gap between expectation and experience in the Chemistry classroom. It has been shown that successful experiences in Chemistry teaching and learning may arise from: understanding and managing difficulties with language; understanding and reacting to the skills levels of students; placing Chemistry in a multidisciplinary context; using modelling – both computer simulations and concrete models, employing active learning and inquiry-based strategies for teaching and learning; and, last but not least, conceding that technology used well can enhance the teaching and learning process. This paper reviews a selection of Successful Experiences and sets the scene for trialling and implementation of some of these with a cohort of first year undergraduate Chemistry students.

1. Introduction
The OECD PISA (Program for International Student Assessment.) is an on-going programme assessing 15 year old students in 30 OECD countries as well as some non-OECD countries.[1] The assessments in reading, mathematical and scientific literacy are repeated on a three yearly cycle. Scientific literacy questions are contextualised and designed to test the scientific knowledge and skills which are essential for full participation in society. [2] The most recent scientific literacy data from PISA places Ireland's 15 year-olds ninth in the list of thirty countries. This was an improvement of five places from the previous study. Despite the strong improvement, business body IBEC has warned Ireland can never allow itself to grow complacent again when it comes to quality education and performance.
While the achievement in the PISA tests is encouraging in relation to the scientific literacy of fifteen year olds, the student demographic in Ireland has changed. Across all school levels there are increasing numbers of non-national students, for many of whom English is not their first language. As well as these international students there are also increasing numbers of non-traditional students, including mature learners who may have limited previous experience of studying science or with few previous formal qualifications. All of these students are not just learning a new Chemistry vocabulary, but many are also learning a new vocabulary in a new language. PISA studies have frequently shown under achievement in science tasks of students with migration backgrounds.
In 2012, students in Irish schools ranked 8th out of the 19 countries that participated in the OECD's Digital Literacy test. Just four countries, Korea, New Zealand, Australia and Japan, had significantly higher scores

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than Ireland. The Government has acknowledged that embedding digital literacy in the school curriculum is an imperative. There is on-going development of ICT infrastructure in Irish schools.
In-service professional development for teachers is underpinning the roll out of technology. This is evident in continuous professional development sessions for science/chemistry teachers. The Professional Development Service for Teachers has hosted Chemistry network meetings in Autumn/Winter 2013 which have included Chemistry Network Meetings. These evening meetings took place in Education Centres throughout the country. Each of these meetings consisted of a workshop on the use of resources produced by a team of experienced Chemistry Teachers, including the following topics: Assessment for Learning: Chemistry apps for personal computer and phones to aid assessment for learning strategies; Chemical Formula Resources; ‘Stimulus to engage activities’ to kick start lessons. Teachers were invited to bring smartphones and/or tablets. [3]
However, in the context of Successful Experiences, technology will only make a difference if used appropriately. A study carried out by the UK Higher Education Academy Physical Sciences Centre in 2008 of students’ perceptions of their university learning experience in Chemistry recorded that electronic instruction was judged by the students to be their least effective and least enjoyable teaching method. [4] The onus is on teachers to integrate technology appropriately to supplement traditional teaching methods.

2. Cultural Diversity: Issues with language

In May 2012, the University of Dortmund hosted the 21st Symposium on Chemical and Science Education, on the theme of ‘Issues of Heterogeneity and Cultural Diversity in Science Education and Science Education Research’. This is just one example of a research and education response to heterogeneity and cultural diversity, two internationally-recognised challenges for education in general. Increased heterogeneity and diversity presents linguistic, cultural and science-specific challenges to science teachers.[5]
The papers in the collection crystallise the problems with the unprecedented levels of cultural and linguistic diversity. Jennifer Miller, from the University of Monash in Melbourne describes an intervention project to redress the inaccessibility of science content language to many students, because of the gaps between scientific and everyday meanings of many words.[6] Linda Riebling from the University of Hamburg in Germany describes research into the methods teachers are using to meet the challenges of cultural and linguistic diversity buy integrating content and language learning.[7]
In the context of the *Chemistry is All Around Us Network* project, one of the publications chosen to illustrate Successful Experiences addresses the issues of linguistics in Chemistry. Rees, Bruce and Nolan discuss the outcomes of research at Durham University into effective teaching strategies to enhance understanding of subject specific language by international and non-traditional students. [8] Teaching strategies with an emphasis on improving scientific literacy were trialled over the course of the academic year 2010/11 in Foundation Level Chemistry. The authors describe various strategies that they employed, including the use of play dough for atomic and molecular modelling, word games, using analogies, and the development of glossaries as well as DARTS (Directed Activities Related to Text).
The outcomes from these initiatives led to the development of an E-glossary to support the development of subject language understanding. The E-glossary was trialled over the next academic year. The result is a glossary of student generated content (with over 100 contributions) explaining scientific terms and concepts in a variety of ways at an appropriate level for foundation students. Each of the terms is described in the relevant technical depth and many of them include an animation or other video. The students as well as the teachers can edit the material. The web portal for the students also includes a section on Scientific Language Skills for Learning. This looks at scientific language in general as well as ways to develop reading and vocabulary and to write scientific reports.

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3. Skills auditing: an opportunity to evaluate and develop Chemistry skillsets

This study by Odilla Finlayson and Orla Kelly in Dublin City University developed from recognition that the transition from school to university can be daunting for many students. [9] While students must have demonstrated a particular level of academic ability to gain entry to college science courses, their skills are rarely audited. The authors suggest that this may result in teachers placing both subject knowledge and skills demands on students. They may be assumed to have certain skills because of their degree subject choice, but in fact might not have particular skills to enable them to make progress with their subject knowledge and understanding, resulting in them making little or no progress, coupled with a feeling of frustration. The recent shift towards context and problem-based learning approaches to teaching the physical sciences may cause particular difficulties for students who have no previous experience of this type of learning as they transit from the rote-learning domination of secondary school.

The authors developed a problem-based approach which was introduced to the Year 1 chemistry laboratory module taken by students on the BSc in Science Education at Dublin City University, Ireland. To better inform the module development and enhance the skill-set of the students it was decided to carry out a skills audit of the first year students at the start of their university course. Forty four students from the 2002–2003 and 2003–2004 cohorts completed the skills survey. This identified what skills students felt they were confident in using, and which skills the students had had little opportunity to develop.

The survey was adapted from the RSC's Undergraduate Skills Record (USR).[10] Various skills were identified in the USR which were seen to be important for first year undergraduate students, such as interpretation of laboratory measurements and observations and using feedback to improve on future work.

Examples of interventions developed for the Problem-based Learning module include: incorporating oral (PowerPoint) presentations into the laboratories; getting students involved with the development of experiments by researching appropriate techniques and procedures using the internet and other resources; the importance of errors and evaluating experimental data was a key focus of laboratory reports and their presentations. This was done in a gradual way, increasing the skill demand across the year-long module. The qualitative result of the trial was that the students seemed to develop skills in the manner anticipated. The authors conclude that more innovative science curricula are needed at school level science to ensure that future science undergraduates will enter courses with more developed skills. A move away from the didactic to a student-centred approach at secondary level Chemistry might encourage better skill development and more confidence to study Chemistry at undergraduate level.

The Undergraduate Skills Record (USR) is now available on-line, in an electronic format that allows students to create an account and record and save their skills continuously, set goals and future targets and generate a skills report at any point.

4. Making connections and underpinning relevance of Chemistry through a multidisciplinary approach

Eilish McLoughlin and Odilla Finlayson described an initiative implemented over a four year period with some seven hundred students in Dublin City University. [11] This intervention recognised issues for new undergraduates: students in first year university science programmes generally must take modules or courses in all science disciplines to a basic level. While curriculum and programme developers see the relevance and interrelations of each of the disciplines to each other and the necessity for a student to have a good foundational knowledge in each subject, the students may often not see the necessity or relevance of the other subjects. Given the low numbers of students taking Chemistry at Leaving Certificate but having to study it at basic undergraduate level there are a number of factors that inhibit performance and connection in the subject.

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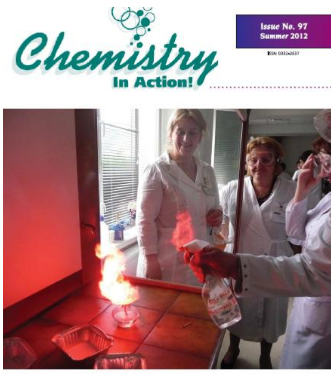
The aim of the lecturers was to develop a module that would highlight the multidisciplinary and interdisciplinary nature of science, that would interconnect the three science disciplines, and that would allow students to develop additional skills. The module content should encourage students to make decisions on the basis of evidence or limited data, to find relevant information, and to form opinions (based on scientific arguments) on a current scientific issue of direct interest to the public. The module was not designed to teach the basic Chemistry and other sciences but to revisit and reinforce content already covered in lectures and laboratories.
The authors surveyed the students and also conducted focus groups over the period of the intervention. They concluded that the students gained problem-solving skills and interacted well within their groups to solve the problems. They note that only forty seven per cent of students agreed that they had sufficient Chemistry knowledge to solve the problems, in contrast to seventy four per cent who agreed that they had sufficient Biology background. This can be correlated to a certain extent with the uptake of the subjects at secondary school level. However, the multidisciplinary active learning approach was met favourably by fifty four per cent of students and the module continues. Problems with significant Chemistry content included: Nuclear Energy, Water Contamination, Genetic Screening, Home Brewing, and Industrial Oil Spill.

5. Active learning Initiatives

The magazine *Chemistry in Action*! Devoted Issue 97 to describing an EU-Tempus funded project – SALiS, Student Active Learning in Science.[12] The central aims of SALiS were to make science education in the participating countries more motivating, more effective in the learning of subject matter and to raise its potential for the promotion of a broad range of cognitive and non-cognitive skills.



SALiS Special Issue

The project aimed to promote science teaching and learning through hands-on student-centred activities, based on the foundations of modern science curricula and pedagogies, in order to raise motivation, to support development of higher order cognitive skills, to produce better learning of science concepts, and to promote a broad range of general educational skills.
Sabine Streller and Claus Bolte described one part of the project, which developed a sequence of lessons situated within the context of weather, climate and climate change intending to facilitate access to the topic based on the everyday experiences of the students. [13] The sequence of ten lessons was devised for interdisciplinary introductory chemistry courses as well as for courses in integrated science.
The authors described one of the major aims of the ten-lesson sequence and a parallel case study as being to make it clear to students that scientific work not only includes conducting experiments, but also finding, working on and evaluating texts and other sources of information. The students should also learn that science answers certain questions but cannot answer every question. A second aim of the project was to motivate

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students to study science and the nature of science by making it relevant to everyday life. Having implemented the lesson sequence they carried out Motivational Learning Environment analyses that show how successful the inquiry-based science teaching approach was, both for the teachers and the students.

In a second article Streller described the contents of one workshop that teachers attended to learn how Inquiry-based Science Education (IBSE) works for themselves. [14] Experiential learning for the teachers of a new mode of instruction is essential for their pedagogical skills development.

The phases of the workshop based on 'Investigating a household product' were described:

Phase 1: Welcome and introduction regarding the meaning of IBSE, goals of the workshop.

Phase 2: Teachers (in small groups) got 'interesting' products from supermarkets (for example effervescent tablets, lactose free milk, nappies) to stimulate questions and to start the inquiry process. During this phase the teachers: talked about the product, formulated questions regarding the product, selected one of the questions, formulated assumptions to the question, planned an experiment to test the assumption.

Phase 3: Involved experimentation about the question, sometimes with the help of a structured worksheet.

Phase 4: In small groups teachers were asked to find explanations for the experiments, to reflect on their assumptions, to find answers for the questions and to formulate additional questions.

Phase 5: In the workshop the teachers had their own experience about how inquiry-based learning could work, without the need for any advanced laboratory equipment but with simple everyday products and materials. The steps of inquiry-based learning were summarized and the participants got the opportunity to discuss possibilities of transfer the IBSE approach into their own universities and classrooms.

This issue of *Chemistry in Action*! Gave plenty of food for thought. While it was centred on the outputs of the SALiS Project, it also included items on low-cost techniques and the value of demonstrations to illustrate Chemistry concepts.

6. The application of technology to enhance chemistry education

Michael Seery and Claire McDonnell from Dublin Institute of Technology were guest editors of a special issue of the Royal Society of Chemistry's Chemistry Education Research and Practice (CERP) in Summer 2013. [15] The editors set the scene for the articles in the special edition in a thoughtful editorial that summarises their standpoint. They acknowledged that while technology in Chemistry education has not always been well-received, a study by Reeves and Reeves suggested that this unpopularity may be because of some implementations that have involved poor design or inappropriate alignment between the technology and the learning objectives. [16]

They selected a number of articles which demonstrate that technology does have a place in Chemistry teaching if it is appropriate and enriching to what is being taught. It will be of benefit if effectively incorporated and if it is a source of explanation, clarification and a means to practice skills and knowledge. Not least it can be a means of delivering timely and effective feedback.

The usefulness of multimedia resources such as simulations in cognitive scaffolding was discussed, with the recurring theme of careful design and utilisation at appropriate points to guarantee maximum pedagogical effectiveness. There are ten papers which include reports on peer-assisted learning, the use of wikis and other collaborative instruments, assessment and feedback, and the use of simulations – among other topics. Like the issue of *Chemistry in Action!* Referenced above, this journal issue gave plenty of material that may be a stepping stone to successful experiences in the Chemistry classroom. Overarching the content is the acknowledgement that ICTs should not be intended as a replacement for good teaching practice but to enhance and support it.

Michael Seery has also written on 'Harnessing Technology in Chemistry Education' in the UK Higher Education Academy New Directions. [17] This article extends some of the ideas from the CERP articles referred to earlier. Seery asserts that the use of technology in teaching might be considered in the context of cognitive load theory as a basis for integrating technology into Chemistry education. Examples of interventions outlined include: pre-lecture or laboratory activities, the use of personal response systems (clickers) in lectures, worked examples in a virtual learning environment, simulations, wikis as collaborative work spaces for peer discussion and peer-assisted learning, screen-casting and pod-casting, and student-generated assessment (some using *Peerwise*).The reality is that while there are many ways the Chemistry teacher or lecturer could integrate technologies into lessons, knowledge of content, pedagogy and technology must interweave to make the resource valuable to both the educator and the students. The phenomenon 'flipped lecture' is also discussed briefly, and again this has to be micro-managed to ensure the students attain the learning outcomes and appreciation of Chemistry intended.

7. Learning from Successful Experiences: testing the realities

In relation to the different issues which have been discussed in this paper, a number of first year undergraduates studying an introductory Chemistry module were surveyed.

The short answer survey included the following questions:

1. What is the highest level of chemistry you studied before this year?
   JUNIOR CERTIFICATE OR EQUIVALENT ʘ
   LEAVING CERTIFICATE OR EQUIVALENT ʘ
2. Please indicate your age group: UNDER 23 years OVER 23 years
3. Is English your first language? YES NO
4. If you answered NO to Question 3, what is your first language?
5. Approximately how often do you access Moodle for Chemistry?
6. Approximately how often do you access YouTube for Chemistry?
7. Have you started to keep a vocabulary list for Chemistry?
8. Are you willing to take part in an evaluation session for the Chemistry is all Around Us portal?

The survey results show that of the 74 respondents, only 30 have studied Chemistry to Leaving Certificate (upper secondary school level), even though they are on one of a suite of degree programmes with Chemistry as a core subject. Twelve of the students are over 23 years of age, i.e. 'mature' students.

English is not the first language for nine students. The primary languages are French (3), Lithuanian (1), Somalian (1), Arabic (1), Persian (1) and Polish (2). There is one deaf student with an interpreter. Forty nine students have started compiling a glossary, as advised at the start of the class year.

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The students' use of Moodle and YouTube is summarised in the table below:

Use	Often	seldom	never
Moodle	46	25	3
YouTube	12	31	30

Moodle is the Virtual Learning Environment platform used in Limerick Institute of Technology. For the Chemistry module the content includes lecture notes, links to relevant websites and video clips. These are sectioned by topic.

The plan from now is to initiate the E-glossary idea for these students by setting an assignment. There will also be trials of different initiatives based on the successful experiences reported by other educators.

Conclusion

Successful Experiences in Chemistry teaching and learning arise from: Understanding and managing difficulties with language; Understanding the skills levels of students; Placing Chemistry in a multidisciplinary context; Active learning and Inquiry-based strategies for teaching and learning; and technology used well can enhance the teaching and learning process. It is not possible to trial all of these modes at one time but a combination of these could be implemented to observe their impact on the learning experience of students. The intention of the author is to qualitatively measure the effects of some initiatives, in particular the E-glossary, on the learning outcomes of a group of Chemistry students. This will be reported in the context of the final phase of the Chemistry is All Around Us Network Project.

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