Introduction

Environmentally-friendly chemistry is central to the development of sustainable chemical industry and manufacturing. Although sustainability is one of the flagships of research and teaching and a major development area of McGill University, there has been little sustainability-focused curriculum development in Chemistry. This proposal delineates an organized effort to develop sustainability-oriented laboratory courses. Teching laboratories are of particular interest in the prospect of developing sustainability because they often constitute one of the most interactive teaching experiences for undergraduate student. Our senior, large-focus and modular teaching lab course, CHEM 392, will be used as a pilot for this development. The advanced, innovative and interdisciplinary nature of the planned laboratory exercises will:

1) Develop a new open-ended and broad model for education in science, with awareness of factors related to sustainability, the environment, energy and solvents.
2) Benefit the sustainability education at McGill University through increased sustainability awareness throughout the Campus
3) Provide a unique opportunity for hands-on sustainability practice
4) Develop excellence in students by providing them a unique experience and skillset based on problem solving, creative and outside-the-box thinking
5) Prepare the next generation of high-quality personnel (HQP) who will work in sustainability-related topics in academia or industry
6) Advance and modernize the chemistry education at McGill, so as to attain a leading position in educating young and versatile personnel
7) Engage students, facilitate their exposure to research and foster interdisciplinary practice within chemistry and beyond

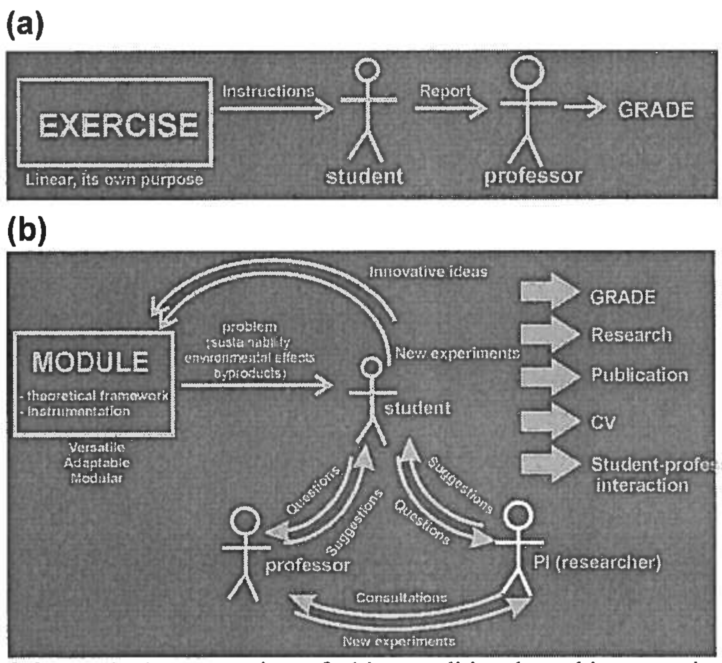
Background

The CHEM 392 Integrated Laboratory is a chemistry laboratory class with a unique structure which is oriented towards developing students' problem-solving skills by providing them with a research-like experience. For over 40 years it has provided a multidisciplinary environment for senior undergraduate students who had to perform a series of modules in absence of time constraint. In September 2011, state of the art renovated laboratories were inaugurated. Over the past year, the different modules of CHEM 392 course were strongly re-oriented towards exposing students to techniques and problems of sustainable and environmentally-friendly chemical synthesis and analysis in the contexts of modern materials science, medicinal chemistry, nanotechnology and environmentally-friendly chemistry (Green Chemistry). This enables educating a generation of young chemical researchers how to integrate their experimental and theoretical knowledge for solving practical problems. The research- and innovation-focused nature of the CHEM392 course is an ideal model because it is based on versatile and modifiable teaching modules that strengthen the student-professor communication and also involve actual researchers in student education. The difference between our

novel vision of CHEM392 modules and the classical linearly organized teaching exercises that was practice before in this course is illustrated in Scheme 1.

This course development aims at serving as a pilot to catalyze sustainability curriculum development throughout the Chemistry Department and, ultimately, beyond.

At this point, the stage is set to expand the existing foundations of the CHEM392 course into a modern teaching laboratory on sustainability- and materials-oriented chemistry. To this end, the professors and staff at the Chemistry Department are already implementing and developing experimental teaching modules that combine modern methods of chemical analysis and separation with exploratory energy- and materials-efficient synthetic approaches. The experimental preparation and instrumental analysis for this progressive effort in chemistry sustainability teaching is performed directly by the PIs, laborator staff and assisted by research facilities. The Chemistry Department is now in an excellent position for such sustainability-oriented curriculum development, with four Green Chemistry identified professors and half a dozen more participating in this effort. The 2011 refurbishment of teaching laboratories with modern instrumentation calls for a pedagogical renaissance that we propose herein.



Scheme 1. A comparsion of: (a) a traditional teaching exercise which is its own purpose and (b) the organization of a module in the CHEM392 class which is dynamic and allows the direct participation of students in laboratory development, along with the laboratory coordinator and a researcher.

Proposal

The requested funds will be used to create an independent environment for the development of laboratory exercises in sustainable chemistry. This will be achieved by acquiring key instrumentation and by hiring trainee students to assist in curriculum development using new modules currenty being developed. In this way, we will develop a teaching laboratory in sustainable chemistry that will be unique in Canada and beyond.

The key outcomes of the proposed sustainability-oriented curriculum development will be:

1) students pre-trained for academic or industrial carreers by providing them access to cutting-edge instrumentation and encouraging lateral and multi-faceted approaches for solving problems whilst keeping a focus on issues sustainability and environmental impact. The CHEM392 will provide an intellectual and instrumental "sandbox" in which the students will be directed towards achieving results of scientific or technological significance, instead of following a traditional and unidirectional laboratory exercise whose only purpose is demonstrating a chemical principle. As a result, the student achievements in the CHEM392 course will be of technological and scientifical value, suitable for publications, student conference communications and even patenting and process development.

2) a point of constructive research-oriented dialogue between sustainability-oriented groups and facilities throughout the University, as the CHEM392 laboratories reach out to other PIs for experiment design (e.g. in Chemical Engineering, Civil Engineering) and materials (e.g. sources of biomass). This will enable a unique design of laboratory exercises wherein a chemical product or a natural resource is funnelled between exercises with a clear focus on sustainable processing and Green Chemistry. Although the focus of this curriculum dvelopment proposal is on the CHEM392, it is expected that in the future this concept of teaching-laboratory-as-research-experience

3) a means to introduce students to cutting-edge and low power demand technologies that enable circumventing chemical analyses, i.e. NMR spectroscopy, powder X-ray diffraction. These two methodologies are excellent examples of sustainability and energy-efficiency inherent to the instruments themselves (PXRD works on a low power 300 W tube, no need for external water cooling; NMRs actually consume very little energy as they're based on superconductor technology - most energy consumption goes into the amplifier).

4) enhancing the communication between students and professors, through actievly involving different PIs into integrating their research areas into the teaching laboratory and assisting the course coordinators (professors and staff) in such segments of curriculum development.

5) actively involving the undergraduate students in curriculum development. This will enable the "real time" development and optimization of new teaching exercises through dedicated and enthustastic students. This is note expected to compete with the current Honors Program as several years monitoring indicates that the pool of high-quality students is sufficiently large. Instead, this will permit the interested students to become more involved and sharpen their experience and CVs.

The requested funds will be used for:

Instruments essential for new "teaching research" modules

1) benchtop high-resolution powder X-ray diffractometer (PXRD) and associated software (ca $60-120K)
2) compact solution nuclear magnetic resonance (NMR) spectrometer capable of rapidly delivering ^{1}H and ^{13}C NMR spectra (ca $150K)
3) supercritical CO_2 extractor (need a price)
4) Bio-Fermenter (*Speak with Karin Auclair*)

we are already getting DLS, but also ICPMS

<u>Student salaries</u>

<u>5 undergraduate trainees</u> for the Winter 2012 semester to assist in the development and optimization of modules in:
"Solvent-free synthesis of metal-organic porous materials"
"Low-energy and solvent-free transformation of minerals into functional materials"
"Biomass extraction of useful platform chemicals eugenol and 1,4-dihydroxy naphthoic acid"

<u>8 undergraduate trainees</u> for the Summer in 2012 to assist in the development and optimization of modules in:
"Biomass extraction of useful platform chemicals eugenol and 1,4-dihydroxy naphthoic acid"
"Chemo-enzymatic transformation of eugenol to ferulic acid"
"Synthesis of the natural products dihydromollugin, mollugin and furomollugin along with evaluation of redox potentials"

Advanced CHEM 392 "teaching research" modules already implemented or are being developed

(*i*) Environmentally-friendly synthesis using magnetic nanoparticles (CJ/AHM, 1st year running)

This module is based on a Green Chem. Publication of 2010 which was recognized as one of the 10 discoveries of 2010 in Quebec (Quebec-Science Magazine). The important reaction of coupling of amine, aldehyde and alkyne provides a one step acces to the important propargyllic amine scaffold. This reaction is catalyzed by magnetic and simple nanoparticles of iron oxide. They can be collected magnetically with a magnet and reused with no loss of activity.

(*ii*) Solar cells synthesis and construction (1st year running)

This module focuses on potential solutions to the quest for sustainable energy sources, and introduces the student to the process of solar cell construction from the point of chemical synthesis to device design, construction and testing. The students construct a dye-sensitized solar cell, also known as a Grätzel cell, in which the light is absorbed by a sensitizer dye, which is connected to the surface of a semiconductor, in a process similar to biological photosynthesis. The module involves the synthesis

of a light-harvesting porphyrin dye as a synthetic analog of the biological agent chlorophyll, and using it for the construction of a cell which is eventually characterized and its efficiency measured.

(*iii*) Solvent-free synthesis of metal-organic porous materials (TF, to be implemented in 2012)
(*iv*) Low-energy and solvent-free transformation of minerals into functional materials (TF, to be implemented in 2012)

Future CHEM 392 "teaching research" modules

- Biomass extraction of useful platform chemicals eugenol and 1,4-dihydroxy naphthoic acid (JPL)
- Chemo-enzymatic transformation of eugenol to ferulic acid (*JPL, Karin Auclair*)
- Synthesis of the natural products dihydromollugin, mollugin and furomollugin along with evaluation of redox potentials (JPL).
- Zero-Valent Iron Nanoparticle for ground water remediation (AHM)

This module will create an opportunity to develop a lab between two departments and faculties. Indeed Subhasis Ghoshal (Department of Civil Engineering) and Audrey Moores (Department of Chemistry) developed a method to perform quantify the efficiency of zero valent iron nanoparticles that are used in large scale for depollution of sites contaminated with chlorinated species, heavy metals and azodyes. We want to turn this research discovery into a CHEM 392 module to expose students to reactive particle synthesis, handling, characterization and reactivity. Importantly this project can be developed across two or more McGill departments to provide a realistic plateform for interdisciplanrity.