A Life Cycle Approach to Chemistry Laboratories at the University of New Haven

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Abstract

The Chemistry Department, housed in the Tagliatela College of Engineering at the University of New Haven, offers numerous courses for chemistry and non-chemistry majors. Most of the courses offered by the Chemistry Department include both lecture and laboratory sections. Laboratories have various configurations regarding student capacity, use of groups in the laboratory, and the range of chemicals and equipment used during experimentation. This in turn means that the cost of supplies, as well as the amount of waste generated by a given laboratory, will vary. The goal of this research was to delve into the economic and environmental impacts of chemistry laboratories on the UNH campus. A life cycle approach was used in order to quantify both of these impacts. Results indicate that *Synthetic Methods* have much higher impacts when compared to other laboratory courses.

1. Introduction

Professors in chemistry programs across the U.S. are responsible for teaching students from all disciplines, including engineering students as well as students from other sciences. Every student in a science related majornrolls in one or more chemistry laboratory courses throughout their undergraduate education. From a big picture perspective, the economic and environmental impacts of chemistry laboratory courses across the U.S. are huge. Therefore, there is potential to make significant improvements in reducing both environmental and economic impacts of such courses. The goal of this research was to delve into the impacts of chemistry laboratories as a whole on the University of New Haven campus, as well as on a course-by-course basis. A life cycle approach was used in order to quantify both of these impacts, which reveals more realistically the effects of chemistry laboratory courses.

2. Background information

Currently, the Chemistry Department at the University of New Haven houses numerous courses for both chemistry and non-chemistry majors. Most of the courses offered by the Chemistry Department have laboratory courses that are taken along with the lectures. For instance, CHEM1115-General Chemistry I (3 credits) is taken along with CHEM 1117-General Chemistry I Lab (1 credit). The topics covered in the lecture for General Chemistry I are then applied in the Laboratory for General Chemistry I. During the Spring 2013 semester for instance, 6 sections of the Laboratory for General Chemistry I were offered to UNH students; each section could enroll up to 24 students. This means approximately 144 students were registered in a laboratory for General Chemistry I course during the spring 2013 semester.

Laboratories are held once a week, and each week a different experiment is performed. In a given semester there are about eight or nine experiments performed in any given laboratory section. Often, these experiments require large amounts of reactants (chemicals needed to perform the experiment), and create a large amount of waste product (which is often hazardous). Some laboratories also generate glass waste on a regular basis as well. Disposal of the glass and chemical waste generated is both expensive and environmentally harmful. Often, at the end of the experiment, all of the waste and products generated in a given experiment are disposed of into a single large waste container, even if the product of one experiment may be a viable reactant for another experiment.

Laboratory set up also varies from course to course. For instance, the General Chemistry laboratories often utilize groups; so about three students will conduct an experiment together. Organic laboratories, on the other hand, consist of sections housing 16 students each. These students are required to work independently on experiments.

2.1. Life Cycle Assessment

Life Cycle Assessment (LCA) is a systematic method that quantifies emissions and environmental impacts of products or processes over their life cycles. Analyzing products over their life cycles enables decision makers to understand the true environmental impacts of their selections.

The theory behind the life cycle approach is that the environmental impact of an item during life (manufacture), death (disposal), and time between (lifespan) can be measured and assessed. The assessment of a chemical includes examining the following: mining or manufacturing the chemical, transporting the components to the plant, and packaging the components in the plant where it was created; transporting it to the university, using it in the chemistry laboratories, disposing of it in the laboratories, and transporting it to a separate waste facility for final disposal. The contributing factors in the calculations for the life cycle approach include: any conventional pollutants discharged into the environment, any pollutants that may cause global warming, hazardous waste or toxins discharged into the air, water, land, or a recycling facility, energy inputs (fuel and electricity), and resources such as ores, fertilizers, or water.

All of these factors are taken into consideration when analyzing any given part of a product's life cycle. Once these factors are calculated and combined, the environmental impact of the product can then be quantified (Hendrickson, Lave & Matthews, 2006).

LCA is comprised of four different stages: goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA), and improvement and interpretation. The goal and scope of a study describes the intended use of the analysis, boundary, functional unit and other items (including temporal aspects). Inventory analysis or LCI involves performing a thorough data collection that quantifies the material, energy, and emissions that occur over the life cycle for the selected functional unit. LCIA expresses the LCI data in terms of environmental impacts. The LCI data is classified into impact categories, such as global warming potential, ecotoxicity, or eutrophication. The interpretation and improvement analysis stage is where conclusions and recommendations are expressed in regard to the goal and scope definition (ISO 2006). All phases are iterative and feedback loops often occur as shown in Figure 1.

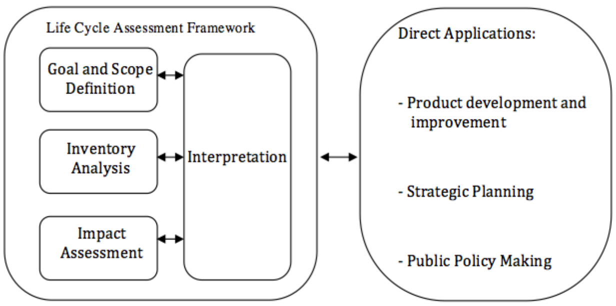

Figure 1. Stages of an LCA (ISO 2006)

Use of LCA offers the possibility of identifying weak points over the life cycle of products and suggests improvements for environmental performance. Governmental institutions, private firms, consumer organizations, and environmental groups use LCA as a decision support tool. The scope of decisions covered by LCA ranges from broad policy changes to specific product or process selection (ISO 2006).

3. Methods

The goal of this project was to quantify the impact of chemistry laboratory courses on the University of New Haven campus economically as well as environmentally. The economic impact of each laboratory was assessed by quantifying the amount of materials (chemicals, safety materials, and glassware) used by each laboratory section for an entire academic year, using the suppliers utilized by the University in order to price each material used, and creating a working total cost for each laboratory section.

The life cycle research is based on the use of the Environmental Input-Output Life Cycle Assessment (EIO-LCA) tool in order to quantify the environmental impact of the laboratories based on the cost of the materials and equipment purchased for the laboratories. Cost information was calculated using the price of the chemicals, glassware, equipment, and safety materials. Current research does not reflect the environmental impact of lighting or heating loads for the laboratory courses studied.

The materials utilized in each laboratory section were then separated into organic and inorganic chemicals (given that chemicals constituted the majority of the laboratory supplies). The two categories were totaled separately for each laboratory section, and these totals were used with the EIO-LCA tool in order to quantify the environmental impacts of each laboratory section, as well as the chemistry laboratory courses collectively.

Both the environmental and economic impacts were expressed for each laboratory and student based on the materials and equipment used. This was done by quantifying the number of students in a given laboratory during the course of a year in order to allocate the total economic and environmental impacts of the laboratory. According to a per student expression results were normalized, making it easier to compare the economic and environmental impacts of different laboratory courses to one another.

4. Results

Data was collected on the various UNH chemistry lab suppliers. Table 1 shows the number of sections of a given laboratory offered during the academic year at the University. These laboratory sections were then broken down into the number of groups the section utilized, the number of students in a group for a given laboratory section (if applicable), and the total number of students enrolled in each laboratory section for the academic year.

Table 2 presents the total cost of supplies purchased for a given laboratory section for the academic year. These supplies include the chemicals used in the experiments for the laboratory section, the disposable glassware that was purchased to run the laboratory, and any other disposable safety wear used. The total cost was then further broken down into a cost per student enrolled in that laboratory section.

Table 1. The breakdown of chemistry laboratories at the University of New Haven

Sections/Semester	**Fall**	**Spring**	**Summer**	**Students/ Section**	**Students/ Group**	**Groups /Section**	**Groups /Year**	**Total Students**
Introduction to General Chemistry	4	4		20	2	10	80	160
General Chemistry I	15	6		24	2	12	252	504
General Chemistry II/Chemistry with Applications to Biosystems		13	1	24	2	12	168	336

Organic Chemistry I	12		16	1	16	192	192
Organic Chemistry II		12	16	1	16	192	192
Quantitative Analysis	5		20	3 to 4	6	30	100
Instrumental Methods		6	20	3 to 4	6	36	120
Physical Chemistry I&II	4	3	15	3	5	35	105
Synthetic Methods	1		16	1	16	16	16

Table 2. The total cost of supplies for chemistry laboratories on campus

Laboratory	**Total Cost ($)**	**Cost per Student ($)**
Introduction to General Chemistry	3,987	25
General Chemistry I	14,976	30
General Chemistry II/Chemistry with Applications to Biosystems	26,270	78
Organic Chemistry I	12,964	68
Organic Chemistry II	6,864	36
Quantitative Analysis	4,982	50
Instrumental Methods	3,376	28
Physical Chemistry I&II	4,292	72
Synthetic Methods	4,416	276

Table 3 shows the environmental impact of each laboratory section as characterized by four main categories: energy usage, greenhouse gas emission, emission of other conventional air pollutants, and transportation impact. Environmental impacts were calculated using the EIO-LCA tool based on cost of supplies for each laboratory section. Each section had its supplies categorized into organic and inorganic chemicals, and then the EIO-LCA was run using the total cost for each category. The total impact of each of the two analyses for a given laboratory section was then added in order to create the total impacts displayed in Table 3. Total impacts were then broken down into a per student impact for each laboratory section based upon the number of students enrolled during the academic year.

5. Discussion of Results

Upon gathering data from the Chemistry Department regarding the chemicals and other supplies needed for laboratories, as well as the number of students enrolled in each laboratory during the school year, a few sections stood out as being particularly more expensive to run on a per student basis than others. The most expensive laboratory section to furnish was *Synthetic Methods*, at a cost of $276 per student. This course however, is not the most expensive section to run overall, but rather only expensive on a per student basis due to the fact that the laboratory section is offered once a year with a 16 student capacity. Comparatively, there were little variations among other chemistry laboratory courses on a per student basis, the range being $25-78.

When comparing the environmental impact of all of the laboratory sections, *Synthetic Methods* had the largest per student impact compared to each of the four chosen areas, which came as no surprise based on the cost mentioned above. The impact per student for this laboratory section was around two times as great as the next largest contributing laboratory section in each of the four areas. *Synthetic Methods* also had a significant energy usage, using about 2520 kilowatt hours of energy per student enrolled. That would be enough energy to power a 100-watt light bulb for almost 3 years.

Materials consumption generates waste and chemicals are no exception. The chemistry laboratories on the UNH campus put out about 6.2 tons of waste per year. Approximately 85% of this waste is hazardous and the other 15% is non-hazardous waste. However, the University of New Haven is considered a small waste generator as far as laboratories go; the campus has around one ton or less of chemical waste stored at any given time.

Quantifying impacts is a necessary step for keeping track of and eventually reducing environmental impacts. Through the use of presented results, strategies and policies will eventually be developed to reduce both the economic and environmental impacts of chemistry laboratory courses.

Almost all of the environmental impact categories considered indicate that *Synthetic Methods* is a hotspot, with a disproportionate amount of impacts occurring on a per student basis, when considering the life cycle of products used for this course. Therefore, this would be a good place to examine potential improvements and alternatives.

Table 3. The environmental impact of each of the chemistry laboratory courses on campus

Laboratory	**Energy**		**Greenhouse Gas**		**Conventional Air Pollutants**		**Transportation**	
	Total Impact (kWh)	Impact per Student (kWh)	Total Impact (kg CO_2e)	Impact per Student (kg CO_2e)	Total Impact (kg)	Impact per Student (kg)	Total Impact (ton-km)	Impact per Student (ton-km)
Introduction to General Chemistry	3,330	21	5,100	32	4	0.02	30,800	193
General Chemistry I	189,000	376	20,400	41	198	0.4	126,000	251

General Chemistry II/Chemistry with Applications to Biosystems	50,600	150	46,600	139	454	1.3	290,000	863
Organic Chemistry I	196,000	1,020	19,300	101	166	0.9	112,000	583
Organic Chemistry II	81,700	425	8,310	43	74	0.4	49,100	256
Quantitative Analysis	50,000	500	5,050	52	43	0.4	29,900	299
Instrumental Methods	19,200	160	2,100	17	17	0.1	13,000	108
Physical Chemistry I&II	43,600	415	4,590	44	42	0.4	27,900	266
Synthetic Methods	40,300	2,520	4,020	251	34	2.1	23,600	1,470
All Laboratories	674,000	5,590	115,600	718	1,030	6.1	702,000	4,290

6. Conclusions

Research described herein should be seen as a first step toward identifying and improving the environmental and economic impacts of chemistry laboratory courses at the University of New Haven. While economic and student enrollment data are deemed to be accurate, environmental impacts can only be described as estimates due to the aggregation involved with the EIO-LCA tool employed. A lack of environmental impact data specific to each chemical used prevents a more detailed environmental analysis. However, such results may be used to focus on courses that need improvement. To that end, *Synthetic Methods* has been identified as a hotspot among the numerous chemistry laboratory courses offered at the University of New Haven.

After calculating the impact that the laboratories have on the environment, the next clear step in this research process is to provide solutions to reduce impacts. This step will be further pursued by looking into green laboratory techniques, comparing practices and waste generation between the chemistry laboratories at the University of New Haven and other laboratories, and attempting to find ways to recycle certain materials used in multiple laboratories.

References

Hendrickson, C., Lave, L., & H.S. Matthews. 2006. *Environmental life cycle assessment of goods and services*. Washington, DC: Resources for the Future.

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Biography

Amanda Spiewak is currently a junior at the University of New Haven, pursuing a double major in Chemistry and Forensic Science. This is her first article, and first summer researching through the SURF program on campus. In the summer to follow, Amanda will be continuing her research on environmental impacts of laboratories, staying in Italy for a month to complete an analysis of the laboratories at the Verona Medical Institute.