Teaching Life-Cycle Assessment at Universities in North America

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Faculty members at universities throughout North America are working to prepare students to meet the growing need for those trained in industrial ecology and related fields. Life-cycle assessment (LCA) is an important component of this training. To gain a better understanding of their activities related to LCA, we sent informal questionnaires in December 1998 to those receiving the *Journal of Industrial Ecology* and others teaching at the university level in the United States and Canada. We report on and assess the results of the questionnaire in this and the forthcoming column.

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The questionnaire focused on the characteristics of courses in which LCA is taught and related teaching resources. The first section contained background questions for all respondents to answer. The second section contained more detailed questions to be answered as time permitted. Although the questionnaire was intended to be broad in scope, because of the method of participant selection it cannot be considered statistically representative of activities in North America.

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Of the 108 informal questionnaires distributed, 26 were returned. Of those returned, 22 respondents indicated LCA is currently taught within a course or is planned as a part of a course being developed. Of the remaining respondents, the reasons given for not teaching LCA were (1) that LCA is outside the scope of current course work, (2) that the respondent's status had changed (a change in university, on leave from teaching), or lack of background in LCA.

Courses and Students

The respondents indicating that LCA is being or will be taught described 29 separate courses. Of these courses, 21 are taught in the United States and 8 are in Canada. Most of the courses are electives, taught on an annual basis. Nine are taught at the undergraduate level, 11 at the graduate level, 8 at a mix of undergraduate and graduate levels, and one, at the University of Wisconsin, is provided at the professional level.

Students taking these courses represent a variety of disciplines. The majority represents engineering functions, some general engineering, and others specific disciplines including chemical, environmental, industrial or manufacturing, materials, mechanical, electrical, systems, biological, and engineering management. Non-engineering disciplines are led by business and environmental policy and science, and also include urban planning, geography, education, English, agricultural economics, human ecology, resource management, biology, industrial design, planning, and public policy. Select courses are offered to a variety of disciplines. For example, the University of Virginia offers *Product and Technology Life Cycle* through the Mechanical Engineering Department to third- and fourth-year students of all disciplines.

LCA in the Classroom

Respondents answered questions concerning how boundary selection, inventory assessment, impact assessment, and interpretation are taught. In the case of boundary selection, students are taught to choose life-cycle boundaries based on the question being asked, the product(s) or material(s) being assessed, the client, data availability, the professor's and student's area of expertise (for example, engineering), and as described in ISO 14040 series and Canadian Standards Association guidelines. Case studies are sometimes used to illustrate boundary selection. For example, Michael Russo of the University of Oregon has his students do a side-by-side LCA of two products and their boundaries are compared. Marlo Raynolds of the University of Alberta teaches a specific selection method based on relative mass/energy and economics.

Inventory Assessment

Respondents were asked a series of questions concerning how students are taught to collect, manage, and assess inventory information. Responses covered streamlined and more information-intensive approaches. In the case of streamlined LCA approaches, several respondents cited the approach described by Graedel (1998) as a means of minimizing quantitative data collection efforts. Alternatively, David Allen of the University of Texas circumvents constraints associated with data collection by providing inventory data for case studies and using a public domain release of SimaPro™, a software-database system developed by PRé Consultants.

In the case of more information-intensive inventory assessments, students are taught to investigate a number of inventory data sources. Several respondents refer students to the U.S. Environmental Protection Agency's *Public Data Sources for the LCA Practitioner* (1995). Others refer students to specific data sources including studies of the U.S. Energy Information Administration, U.S. National Laboratories, Statistics Canada, and United States Census and United States Environmental Protection Agency (U.S. EPA) websites, U.S. EPA sector notebooks, LCA software databases, and trade journals. Michael Russo of the University of Oregon urges students to contact companies directly to obtain inventory data and to understand organizational issues in LCA.

Spreadsheets were most frequently mentioned as a means to manage inventory data. Robert Anex of the University of Oklahoma uses spreadsheets to supplement his use of LCAD, a U.S. basic commodity database developed by Battelle-Pacific Northwest National Laboratory. He uses LCAD data within spreadsheets and believes spreadsheets have advantages in verifying mass balances in process modeling. Clinton Andrews of Rutgers University suggests his students use the "notes/comments" feature for data documentation.

Methods to assess inventory data uncertainty range from qualitative to quantitative. On the quantitative side, sensitivity analysis, probability and confidence intervals, and scenario analysis are used. Specifically, Benoit Cushman-Roisin of Dartmouth College has students investigate how variations impact the bottom line.

Impact Assessment

Respondents were asked a series of questions concerning what impacts to consider, how to assess these impacts, and where to obtain supporting information. Environmental, resource use, and economic impact categories were most frequently recommended for consideration within impact assessment. Additional impact categories include occupational and non-occupational health and safety, and social welfare.

Impact assessment methods include the use of loading assessment by impact category, equivalency factors, and the Volvo-EPS-Environ-Accounting Method. Specifically, Marlo Raynolds of the University of Alberta identifies stressor categories, rolls up inventory results within categories, and uses Monte Carlo Analysis to quantify the propagation of error. Several respondents identify the assessment and presentation of impact-related data uncertainty and time dependencies as problematic.

Resource consumption was the most often-considered impact indicator. Other impact indicators frequently used include global climate change, human toxicity, acidification, eco-toxicity, stratospheric ozone depletion, photochemical ozone formation, and nutrient enrichment. Less frequently, respondents indicated the use of work environment, solid waste generation, water quality, oil spills, and radioisotope impact indicators.

The availability of impact-related data sources is a problem and is sometimes used as a topic of class discussion. Sources suggested for investigation by students include state-level environmental indicator reports and comparative risk projects, a variety of state-of-the-environment reports and U.S. EPA and Environment Canada databases. Specifically, David Allen at the University of Texas has students examine an application of the Volvo-EPS-Environ-Accounting Method as a case study.

Interpretation

Qualitative or semi-quantitative techniques are most frequently taught to students as a means to assess and present LCA results. Clinton Andrews of Rutgers University has students apply a multi-criterion trade-off framework used in a decision support mode to provoke discussion rather than the identification of an optimum solution. Benoit Cushman-Roisin of Dartmouth College has students compare bottom-line scores, rank alternatives, and discuss the primary reasons behind rankings.

Class Assignments

Class assignments include redesign activities and product comparisons. Susan Carlson-Skalak of the University of Virginia asks students to redesign a common product such as a wine opener or stapler based on user needs and environmental impacts from a streamlined LCA. Dixon Thompson of the University of Calgary cited two assignments: first his students select a simple product/package and sketch out the LCA process and second, his students compare the use of wood, steel, and concrete within electrical power distribution systems.

Several respondents use a group approach to class assignments. Specifically, Benoit Cushman-Roisin of Dartmouth College has groups of three or four students carry out a term-long project on design for environment (DfE) that includes the redesign of a product or process. The culmination of the project is the comparison of the LCAs performed on the existing product/process and its redesign. Clinton Andrews of Rutgers University uses a game simulation format in which the students negotiate their position. Also, Michael Russo of the University of Oregon has his students compare functionally equivalent products.

Teaching Resources

Respondents indicated that books are the most frequently used resource for teaching LCA. Graedel & Allenby's *Industrial Ecology* (1995) was cited most often. Other books are listed in figure 1.

In addition to books, several respondents cited case studies as an important teaching resource. Case studies cited by respondents include: plastic vs. paper cups, electricity-sector policy analysis (demand vs. supply-side investments), pulp and paper processing,[1] alternatives to lead solder and baking soda, steel vs. aluminum, and virgin vs. recycled metals in automobiles, the set of McDonalds-and-the-Environment[2] case studies, and several studies by Franklin Associates. Reasons for the use of these case studies include their brevity, because they have been developed into educational modules, because the subject matter is familiar to the professor, or simply because the data have been published. Robert Anex of University of Oklahoma uses several case studies to show variation of process and the extent to which interpretation and context are critical to conclusions.

The majority of respondents found the resources available insufficient to teach LCA. Ideas for additional resources include: case studies (e.g.,

- Allen, D. T., K. S. Rosselot. 1996. *Pollution Prevention for Chemical Processes*. New York: John Wiley & Sons.
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- Russo, M. 1999. *Environmental Management Readings and Cases*. Boston: Houghton Mifflin.
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- White, P., M. Fanke, and P. Hindle. 1999. *Integrated Solid Waste Management: A Life Cycle Inventory*. New York: Chapman & Hall.

* Available at http://www.eea.eu.int:80/Projects/EnvMaST/lca/download.htm

Related learning materials are available at http://www.tek.fi/step/publications.htm#assessment

Figure 1 Books used to teach LCA.

more comparative case studies, those using ISO 14000 guidelines, and institutional case studies for use in engineering, public policy, and facility design), accessible impact information (e.g., a website where students could download regionally corrected unit impacts of standard activities such as electricity and transportation use), homework and test exercises, improved textbooks, and easy-to-use and affordable software. Also, resources should not be oversimplified.

Barriers to Teaching LCA

In addition to the need for teaching resources, barriers to teaching LCA provided by respondents fell into four general categories:

- **Administrative barriers** including lack of administrative support and little room in curriculum for additional concepts;
- **Application barriers** including the limited use of LCA in professional practice;
- **Procedural barriers** including the as yet undefined nature of the LCA protocol and the necessity for many judgments; and
- **Temporal barriers** including the large time cost of assembling data and lack of simple enough examples to finish within 1–2 class periods.

Student Experiences

Students walk away with a variety of impressions of the LCA process. Value is seen in the consideration of product disposal and social issues. Furthermore,

- Benoit Cushman-Roisin of Dartmouth College stated that by the end of the course, students view LCA as a decision-making tool whenever "apples and oranges" are to be compared. But, students also recognize a need to consider LCA and Total Cost Assessment results simultaneously.
- Robert Anex of University of Oklahoma stated that his students appreciate life-cycle perspective but recognize the large overhead involved in analysis. Those practicing now appreciate software tools more than they did during the course.

- Clinton Andrews of Rutgers University stated that those trained in economics are typically skeptical: they want to boil down to a single benefit/cost ratio. He finds engineers and planners to be more comfortable with the process and that planners want procedural and substantive rationality and typically do not believe experts' views should be privileged.

This column has summarized the results of the informal questionnaire including information on approaches to LCA, relationship of LCA to other courses, examples, case studies and resources used, barriers, and additional resource needs. In subsequent columns we will discuss the adequacy of resources, directions of current research, and ways to overcome barriers. We solicit your reaction and insights into other topics relevant to application of LCA in North America.

Notes

1. Specifically, the Canadian Standards Association Z810-96 LCIA for Pulp and Paper Production Process.
2. Available at http://www.umich.edu/~nppcpub/resources/compendia/ind.ecol.html.

References

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