After 10 years and 300 students. Our LCA teaching experience, *Anne-Marie Tillman & Henrikke Baumann, Environmental Systems Analysis, Chalmers University of Technology, S-412 96 Göteborg, Sweden.*

Our LCA teaching experience started with organising the first LCA course in Sweden in 1992 – it was a course on a national level for doctoral students. After that, we continued with one LCA course each year for undergraduate students (3rd or 4th year students). During the first years (1993-1995), the course was given as a summer course for international students. But since 1996, the LCA course is given as an ordinary, elective course for all engineering students at Chalmers, attracting some 30 students every year. Most of them are Chalmers students, but a number of science students from Göteborg University, doctoral students and working engineers from around Sweden also find their way to our course. In addition to the LCA course, we also give "the 2 hour lecture" orientation about LCA in the compulsory environmental course for 1st / 2nd year students at Chalmers, and we have run around 25 LCA projects as MSc diploma projects. Based on our broad experience, we will talk about how LCA education can aim at different levels of understanding (from the "know about" level, via the "reflect critically" level, to the "carry out" level) and what this implies concerning reading material, exercises, the use of LCA software and LCA manuals. We will also talk about student reactions to working in interdisciplinary groups and with open problems.

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Introduction

The most poignant observation after ten years of teaching LCA is that there is still great demand for LCA education. In addition to giving a basic, "pure" LCA course, we receive a steady flow of requests for LCA packages integrated in other courses and requests from industry to support their capability building.

Over the years we have tested different approaches to teaching as well as numerous existing LCA guidelines and texts. Some approaches and texts have worked, while others have not. An important finding is that LCA teaching needs to take on different forms and have gradual aims, since engineers encounter LCA in a number of different ways (as managers, product developers, design engineers, purchasers, independent consultants, etc). We distinguish between the "know about" level, the "reflect critically" level and the "carry out" level. In the following, we will report on our experiences concerning useful approaches and shortcuts in relation to the different levels of ambition.

Our background

Our LCA teaching experience started with organising the first LCA course in Sweden in 1992; it was a course on a national level for doctoral students. After that, we continued with one LCA course each year for undergraduate students (3rd or 4th year students). During the first years (1993-1995), the course was given as a summer course for international students. But since 1996, the LCA course is given as an ordinary, elective course for all engineering students at Chalmers, attracting some 30 students every year. Most of them are Chalmers students, but a number of science students from Göteborg University, doctoral students and working engineers from around Sweden also find their way to our course. When we say 300 students in the title, it is these students we refer to. However, were we to count all students and engineers we have taught, the numbers would be in thousands.

In addition to the LCA course, the department also gives (has given):

"the 2-hour lecture" orientation about LCA in the compulsory, basic environmental course for 1st / 2nd year students at different engineering programmes at Chalmers. Approximately 600 students/year meet us this way.

LCA packages (lectures and exercises) in other courses, many at other universities, mostly in Sweden. These LCA packages are integrated in courses on for example environmental management and product development. In total, around 10 different universities have received these packages. Some of them are given on a regular basis, while the remaining have received help under a shorter period to start up their own LCA course.

- Industry support. These education packages are tailor-made, reflecting the specific requests from different companies. They encompass single lectures on specific topics (e.g. weighting, allocation, LCA implementation), whole education packages taught to broader audiences and support in LCA projects.
- MSc diploma projects. We have run around 25 such projects, covering for example LCA studies, methodology development and studies of the usage of LCA in industry.

Our teaching is based on research into LCA methodology and practice as well as hands-on experience from performing LCA studies.

Different levels of understanding

The three levels, "know about" level, the "reflect critically" level and the "carry out" level, differ in depth of understanding and meet requirements in different professional contexts.

Knowing about the existence of LCA enables the engineer to assimilate life cycle thinking, recognise LCA results when he/she sees them or even to ask for them. Typically this is a 2-hour lecture covering what LCA may be used for in different contexts. It also covers LCA methodology briefly, concentrating on methodological pitfalls. LCA studies are used extensively to illustrate methodology as well as applications. Simple exercises, e.g. drawing the flow chart of a well-known product or definition of functional units may be conducted on the blackboard. Students are encouraged to think about in what ways they may themselves encounter LCA in their future role as engineers, and what additional LCA training they might need.

The capability *to critically reflect on LCA methodology* allows the engineer to work more actively, but still indirectly, with LCA in many situations. For example, he/she can act as a commissioner of LCA studies, organise LCA activities and read LCA reports in order to extract useful implications.
This level of LCA understanding is often conveyed in tailor-made LCA packages to industry and as integrated parts in courses at other universities. These packages vary from one to three full days and build much more on dialogue with the students. Depending on the type of company or course, different professional roles are explored.

A commissioner needs to be able to engage in dialogue on a qualified level with the LCA practitioner in order to obtain an LCA study addressing their particular problem. In such a dialogue the LCA commissioner formulates the goal and the practitioner then suggests the scope, e.g. system boundaries, functional unit, format for result presentation. The commissioner must be prepared to discuss these issues with some level of detail. Commissioners are found in industry as well as in public administration. An example from public administration is the choice between LCA, material flow analysis and ecological risk assessment to support the development of a public policy on e.g. recycling.

A manager must be aware of organisational choices concerning the application of LCA. In industry, a typical managerial choice may be to decide whether product designers should execute simple LCAs in the form of matrices themselves or internal consultants execute more detailed LCAs.

Product developers and purchasers need to be qualified readers of LCA results.

As compared to the previous level, more lectures are given and exercises are conducted on a more individual basis. The lectures cover methodology in more depth and more examples of LCA studies are presented and compared. These are used to stimulate discussion and reflection. Examples of additional exercises are goal and scope definition, critical reviewing of LCA reports and interpretation and comparison of environmental product declarations.

The competence to *carry out* an LCA requires detailed methodology knowledge and skills in e.g. computation, data collection and documentation and ability to adapt presentations to different audiences. The competence to *carry out* an LCA is best taught by learning by doing. According to our experience, this can be accomplished with prepared, ready-made cases. Also, understanding is best achieved without LCA software. Unfortunately, it has been difficult to find literature that works as teaching material.

It is important to train other professional skills than methodological knowledge. There are several professional situations with varying contexts and roles for the LCA practitioner, for example the definition of goal and scope together with the commissioner, development of product specific requirements (PSRs) for environmental product declarations, data collection, building up databases and promotion of life cycle thinking.

Our 5 credits course aims at the competence to carry out an LCA. It includes integrated lectures and exercises on methodology, presentations of LCA studies and guest lecturers from industry. We have several exercises to gradually build up the ability to carry out an LCA. Before a full LCA project is performed smaller exercises are done on for example goal and scope definition, functional units, impact assessment, data collection. A simple "step-by-step LCA" prepares for the full project. The LCA projects are designed so that the students are given a role as practitioner in a realistic context (in industry or public administration).

After the 5 credits course, students should be able to carry out full-blown LCA projects in for example their MSc diploma projects.

Our experiences

Over the years, certain topics have recurred in the discussions during course planning and course evaluation. The topics are choice of reading material, type of exercises and the use of LCA software. With

time, we have come to form an opinion on teaching methods based on our experiences from the classroom. In the following, we will elaborate our thinking on this in relation to the three levels of LCA understanding.
Reading materials

There are many LCA texts written as presentations of LCA and even as "manuals" and "guidelines", and one would think that they could support learning LCA by doing. We have used the SETAC Code of Practice (SETAC, 1993), the UETP-EEE textbooks (Pedersen, 1993; Pedersen Weidema, 1994), the Nordic guidelines (Nord, 1995) and the ISO standards (ISO14040-43). We have also considered the use of CML's guide (NOH, 1992), the LCA anthology edited by Curran (1996), the Swiss anthology (Schaltegger, 1997) and the Danish EDIP manual (Wenzel et al, 1997). On occasion, we have also used research papers as part of the course literature.

Experience shows that research articles are too narrow in scope for the students to get an overview. They are also written as part of the scientific debate, with few real-life examples, which makes them difficult to access for the students. However, research articles can be usefully accessed at the level of a MSc diploma project.

The ISO standard on LCA is comprehensive with regard to LCA methodology. However, the standard requires much previous knowledge to make sense to the students. In addition, the text in the standard suffers from being partially inconsistent.

The presentation of LCA given by the anthologies was considered too fragmented and non-uniform for the students to obtain a coherent overview. Furthermore, the anthologies are written as presentations of LCA rather than as textbooks, and consequently they contain no exercises.

Our experience from using the Nordic guidelines as reading material is that the text is difficult for the students to access. We believe that this is due to that, like research articles, the Nordic guidelines were written as part of the scientific debate. In line with this, the CML guide was considered to be more of a research report that is difficult to read without previous knowledge. It turns out that the ambition for completeness is in conflict with the ability to give an overview. The Danish EDIP-manual, finally, was considered more pedagogical. However, it addresses an industrial audience and is focussed on one of the LCA applications, product development. None of these is produced in greater numbers, or with the continuity suitable for student literature.

The only texts written as textbooks, the UETP-EEE books, are unfortunately out-dated by now.

It may be established that presented literature hardly fulfils need of the carryout level, even less the lower levels of understanding. This has prompted us to develop our own teaching material.

Exercises

Over the years, we have introduced additional exercises. Student learning has thus been improved. We have also found that it is possible to design and carry out exercises on all three levels of understanding.

When learning to carry out LCA it is necessary to prepare with smaller and stepwise exercises to give a gradual build-up of LCA competencies. For example, in our first LCA course the LCA project was introduced to the students immediately after introductory lectures on methodology. Although they understood LCA on a principle level, they were overwhelmed by the task. The year after, we had prepared "A beginner's LCA", which takes the students through the procedure step by step in two hours. The same procedure could then be applied in the bigger projects, and since the students were able to overview the whole procedure they were much less frustrated. Since then, additional exercises have been added to develop methodological understanding (e.g. goal and scope definition, functional unit, allocation, impact assessment) and to train various skills (e.g. data collection, critical reviewing).

The smaller exercises are useful, but it is only in the LCA project that they realise the full width of an LCA. For example, they need to deal with contextual problem formulation, time prioritisation, control over a huge data set and calculations, preparation of presentable, transparent reports adapted to the commissioner and the formulation of defendable conclusions and recommendations.

It is important that such a project is realistic. One way of achieving realism is through sending out students in "real life" projects. The advantage is that students then meet a real context and the full complexity of an LCA project. The drawback is that students, within the given time limits, never get to accomplish a full project. The main reasons are incomplete technical information, data gaps, inability to handle many different data suppliers at a time and finding their way to the right person. As a consequence, it is difficult for the students to get to the point where they can draw meaningful conclusions. The level of frustration is not even realistic; it is exaggerated. In addition, as a teacher it is difficult to defend the yearly pestering of data suppliers.

We have chosen an alternative way. The students are given projects that have been constructed based on old case studies. Thus they contain a full set of data. Realism has to some extent been sacrificed for the possibility to accomplish a project within time limits. For instance, the problem as well as the data is somewhat out-dated. Data collection and documentation becomes artificial.

Contact with "reality" can be obtained for all three levels of understanding. Especially when the purpose is to introduce the students to the LCA concept, it is not constructive to send out them to do real life projects. There are other ways of putting the students in contact with "reality": qualitative LCAs, real data collection for one activity in the life cycle, and critical reading of published LCA report.

Use of LCA software

A commercial LCA tool is essential for the LCA practitioner. However, their usefulness in teaching is less straightforward. When students are to know about LCA, it can be sufficient to mention that there are a number of LCA software. A classroom demonstration can be carried out as well as hands-on experimentation in order to illustrate the life cycle concept. However, if the aim is deeper methodological understanding, then the use of LCA software may be counter-productive. Our experience is that the students draw nice flowcharts, but never see the underlying calculations and the implicit methodological choices. Even worse, the students never challenge the results obtained by the software when in the process of learning to carry out LCA. An LCA software becomes again useful for more accomplished students in their MSc diploma project. At this level, the students are better at checking the reasonableness of results. On several occasions, our students have found "bugs" in commercial software (even as late as 2001).

In our 5 credits course, students are required to solve mass balances by hand and to use ordinary spreadsheet programmes. This is the only way we have found to confront them with the methodological choices involved in flow modelling and enable them to double-check and correct calculations. For calculations to be manageable, the LCA projects given to the students cannot be too large in terms of number of activities in the life cycle.

Student reactions

At all three levels of understanding, the small exercises contribute to students' learning, but also to their delightful surprise of attaining insight in the "hidden" systemic properties of everyday products. At the same time they discover the possibility of describing environmental matters in a systematic manner. Merely looking at a flowchart and discovering the implications of cradle to grave may be deeply satisfying for beginners.

Generally, students' reactions are very positive until they get to carry out their first LCA project. Then frustration begins...

The first complaint usually concerns the composition of student project groups. The students are reluctant to collaborate with engineering students from programmes other than their own, or even worse, with students from the natural science programmes. Eventually, in the course evaluation, they tend to point out the positive experience of multi-disciplinary project groups.

A more serious frustration is caused by the engineering students' inexperience of working with open problems. Engineering students are trained to *solve* problems. These problems can be very complicated, but they are typically defined beforehand. In the course of an LCA project, it is necessary to read the context and extract a workable problem definition, workable in the sense that it can be answered through LCA modelling. The students' frustration may be prevented with the help of a preparatory goal and scope definition exercise. Proper supervision is essential at this stage in the project.

Students encounter problems with modelling also during the inventory analysis. They often have difficulties in distinguishing between the model and the modelled industrial system. For example, they confound data gaps with system boundary definition.

However small the contact with "reality", it leads almost inevitably to frustration. Even data collection for a single activity, be it from industry, the Internet or LCA reports, is painful.

The use of ready-made LCA projects inherently leads to that both problem and data are somewhat old, but not as old as the students would have them. Students refrain from suggesting improvements using this argument. In doing this, they reflect a naivety regarding the pace of development of environmental performance in industry.

Lessons learned over the years

We have observed a number of more or less useful teaching methods. Problems in relations to LCA teaching are often related to unclear goals. We propose a model with three levels of understanding (the "know about" level, the "reflect critically" level and the "carry out" level) from which appropriate teaching methods can be developed.

We strongly discourage the use of real-life LCA projects, especially when the sole purpose is to introduce the LCA concept to students. Real-life contact can be achieved in many other ways.

Frequent use of examples (LCA reports and case studies) in lectures as well as a coherent reading material improves student learning. LCA "manuals" have been found to be too difficult to access for the inexperienced reader.

There are useful exercises for all level of understanding. Smaller exercises are also useful before conducting a full LCA in order to prevent student frustration. The use of LCA software in the process of learning to carry out LCA should be considered with care, since it tend to obscure student perception of methodological choices.

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