

Incorporating Standards Education into Courses on Environmental
Management and Sustainability¹

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Abstract: This project modified content in a popular free open access textbook on environmental life cycle assessment (LCA), which has been standardized under the ISO 14000 environmental management system family of standards. The goal and intention of these content modifications was to improve student understanding of the role of standards in promoting environmental sustainability. The research involved a pre-assessment of student knowledge about the ISO 14040 Life cycle Assessment standards, examining the coverage of standards materials in courses, and assessing gains in standards knowledge through a post-assessment. Participants included students from several universities where courses in LCA, environmental management and sustainability are taught annually. Over the period of research, we expanded and enhanced the content related to engineering standards, the standards making process and organizations, the ISO 14040 LCA standards, and its uses in professional practice. Comparisons are made in individual student gains pre- and post-course, and in cohort gains prior to changing the content in the textbook.

¹ This report is a derivative work of a paper published by the authors in the proceedings of the American Society for Engineering Education (ASEE) [10]

Introduction

The ISO 14040 standard for Life Cycle Assessment is a foundational standard for practitioners in the area of environmental benchmarking and comparative assessment. Students studying environmental management and sustainable engineering need to be aware of this standard and have a more in-depth understanding of its definitions and requirements as they move to the workplace. Our work developed materials on ISO 14040 standards to be used in course materials, with an investigation of how including these materials might impact student learning on the topic. This paper demonstrates our method for enhancing standards education through materials development. We first discuss the development of standards for benchmarking and comparative assessment, and various courses and curricula that include these materials. Next we describe our process for assessing student knowledge of standards and developing standards based material. We end with some lessons learned about the process for developing materials on standards.

Project and Importance

There is increasing global demand for benchmarking and comparative assessment of the environmental performance of companies including that of specific products and processes. This information is becoming more important to consumers and decision-makers in industry, society, and government worldwide. These performance measurements have been achieved through development of metrics and methods to consider use of energy and other material and resource inputs, as well as outputs such as air and water emissions and releases like wastes. A relatively recent component of this performance assessment has included consideration of sustainability, which is often broadly defined as the ability of current generations to meet their needs without compromising the ability of future generations to meet their needs [1]. Sustainability has more colloquially been defined as the interaction of economic, environmental, and social factors. Companies have thus been more broadly seeking ways to report their performance across this holistic view of their operations and led to outcomes like annual sustainability reports for major corporations around the world. For companies operating in certain jurisdictions, reporting of this kind is mandatory, but in most cases is done on a voluntary basis as a means of driving shareholder value by creating a perception that the company is proactively measuring their performance and developing competitive advantage.

At present, companies are largely focused on reporting the energy consumption, water use, and greenhouse gas (GHG) emissions associated with their company overall, as well as on a product or process level. The US EPA's GHG Reporting Program (GHGRP) launched mandatory reporting at the facility level for many energy-intensive sectors, which has caused approximately 10,000 facilities per year to quantify their carbon emissions. In support of such efforts, global bodies have defined methods to quantify the

energy, environmental, and other impacts at various levels of resolution. Companies are reporting their performance at unprecedented levels to agencies using mandatory and voluntary data systems.

At the company level, documentary standards have been created by groups like the World Resources Institute (WRI) to define how firms should measure their overall “carbon footprint” of GHG emissions from their own in-company activities (called scope 1), that of their energy suppliers (scope 2), and for all other upstream and downstream activities (scope 3) [2], [3]. Once the emissions have been quantified, firms report resulting GHG emissions through voluntary or mandatory data collection efforts like the Carbon Disclosure Project or EPA's GHGRP. Building on the foundation of these standards, WRI has also developed standards for reporting GHG emissions at the product-specific level [4]. Finally, ISO has developed standards specific to carbon and water footprinting (ISO 14067, ISO 14046).

The aforementioned standards fundamentally depend on the definitions and comprehensive environmental analysis contained in the ISO 14040 standards for life cycle assessment (LCA). These standards, first formalized via ISO 14000 for environmental management systems in the 1990s, provide a systematic quantified inventory and impact assessment of the environmental implications of products in every life-cycle stage: materials extraction, manufacturing, use, and ultimate fate of the product (reuse, recycling, incineration, or landfilling). Based on the environmental assessment, improvements could be made to products or processes to minimize their environmental footprint over their life cycle.

Since the LCA Standard has created all of the underlying definitions and terminology to be used to assess environmental performance for specified functional units, it was the natural building block for all of the other standards mentioned above. Thus, the ISO 14040 LCA standard should be a focus of instruction for practitioners and students in this field.

U.S. Sustainability Courses and Curricula

Despite the large investments in the underlying standards, as well as supporting methods to implement them and to create robust decision tools, most students are unaware of the critical role of standards and the standardization of methods needed to support all of these process, product, and firm-level performance measurements. Results of national sustainable engineering curriculum assessments in which our team collaborated showed that five years ago there were only a few whole semester undergraduate or graduate courses on life cycle assessment (LCA) in 100 engineering colleges in the US. Most science and engineering programs that discussed or taught LCA did so in 2-3 lecture course modules focused on LCA data collection and organization and simple modeling exercises [5], [6]. An identified gap was that there were no centralized teaching resources such as textbooks or lecture materials available in this domain.

Based on this outcome, members of our team led the development over the past several years of a free online textbook [7] (available at lcatextbook.com) to teach various concepts associated with LCA to undergraduate and graduate students. It has been developed to support entire semester LCA courses, as well as the short course modules historically used, and short course or executive education formats. Chapter resources include learning objectives and homework questions, as well as tailored interactive spreadsheet and web models. For instructors, we have developed PowerPoint lecture note files, and have been developing video lectures (approximately 1 hour total per session). We developed and disseminated all of these materials in electronic and web-based formats to ensure a long-term and low-cost sustainable delivery platform. In this report, when we refer to 'the textbook', we refer to not just the text itself, but also this entire ecosystem of learning resources.

As a result of these investments, the textbook has already been adopted in around 50 undergraduate or graduate full-semester courses at universities in the US, leading to thousands of downloads of the textbook, with adoptions increasing every semester (e.g., the Spring 2018 semester inspired 2,000 full book-equivalent downloads). These courses are in science, engineering, social science, and management departments. The online textbook and website is being used on all continents, and is being translated into three languages. In short we have curated an international network of professors and professionals using the LCA textbook as well as the supplemental learning resources that form a natural audience for educational material.

Original Project Goals

The textbook has always included some content related to ISO 14040. However, we recognized the need for further developing this content to make it more robust and useful for future practitioners. Better understanding of both the standards development process and the standards text and uses was needed. For example, while the details of the ISO LCA Standard were a central component, the development of the specific Standard as well as the general way in which Standards are created, or in the case of greenhouse gas protocols the interaction of multiple standards, was not originally a part of curricula or course content.

Through our project, we sought to develop the standards content and fill a significant gap in the teaching of environmental performance assessment (such as LCA) by formalizing curricular elements associated with the development of the underlying standards, as well as how those standards enable the comparative assessments of processes, products, and companies. This would allow many people, beginning at the undergraduate level, to understand the important role that standards have played in this domain. They will also see how the critical interconnected development of standards and practice are enabling

innovative sustainable opportunities to understand and improve environmental performance. Specifically, based on our unique experience in assessing curricula needs and developing teaching resources related to LCA, we identified the following four aspects to be integrated into newly developed materials:

- 1) The historical drivers for standardization in the environmental performance domain, the organization of the various entities (ISO, ASTM, etc.) that interact to produce standards, and the role of standards in increasing competitiveness and spurring sustainable innovation of products, processes, and firms.
- 2) The difference between documentary and measurement standards. In the environmental performance domain, they are generally *accounting* rather than *measurement* standards. While the overall carbon footprint of a company may be comprised of many individual components that can be measured in some way (e.g., tailpipe or stack measurements of emissions), the overall combination is done through accounting methods.
- 3) The 'map' between the standard and the study document. Current courses mention the standards, their development, and use, but do not directly integrate use of the standard in the course. This presents the Standard as secondary to the methods used, even though following the standards is essential for an ISO-compliant LCA or carbon footprint report. Since many students will go on to be practitioners by completing LCAs based on the standards, or reviewing LCAs according to the standards, it is important for them to recognize the complexity and rigor these standards have.
- 4) Understanding the role of professional peer review for standard compliance. ISO LCA studies must be peer reviewed by external parties if they will support comparative assessments intended for the public (which many are). Learning how peer review is done, and the role of critical feedback, is a critical piece of the standard process. This means both writing peer reviews and reading/comprehending existing reviews.

Project Evaluation and Assessment

The research involved study over a two year period. We asked faculty who taught a full-semester life cycle assessment course that used our textbook as a resource to participate and eleven faculty at different institutions volunteered. These institutions included eight doctoral, highest research level universities, and one each of doctoral - higher research, doctoral - moderate research, and masters institutions. The courses included mostly courses for graduate students but included undergraduate enrollment. Students from eight institutions completed assessments.

In year one, we collected pre- and post-assessment survey data from students in courses at these institutions. Year one data provides a baseline of knowledge in standards content for life cycle assessment. At the end of year one, after discussion with LCA practitioners and standards

colleagues, we made changes to the textbook to improve standards content. During year two, we repeated the pre- and post-assessment surveys for students in the courses. Thus we have pre- and post-assessments of a cohort of students before the “intervention” of textbook improvements, and pre- and post-assessments of a cohort of students after the “intervention” of textbook improvements.

The pre- and post-assessment included a set of questions to gauge student knowledge and awareness of both life cycle assessment generally (12 questions), and life cycle assessment standards specifically (24 questions, full assessment provided at end of the paper). The survey instrument was the same for both assessments, with the post-assessment also including questions about the chapters of the textbook that the student read and which ones were assigned. The latter questions help us to identify whether the standards content was emphasized in their particular course or not, at least according to the student.

Students were solicited via an email forwarded from the study team to the course instructor who then forwarded it to their students either directly or through a course management system. In the surveys, students were asked for their name, email, and institution in order to match pre- and post-assessment results. We also used emails from the pre-assessments to directly email students the post-assessment link. A total of 135 students completed the pre-assessment, and 35 students completed the post-assessment, with 29 students completing both surveys. Students were not compensated for their time, and unless their instructor made other arrangements they were not rewarded or penalized in their course for completing either assessment. We did not share information about students completing the assessment with course instructors.

On the pre-assessment, we find that students across all three semesters had similar prior knowledge about life cycle assessment topics and life cycle assessment standards issues. Mean scores were 21, 21, and 20 points (out of 36, where questions with multiple subcomponent elements could be worth multiple points) for students from the three semesters, respectively. We divided the questions on the assessment into “general LCA knowledge” questions and “LCA standards knowledge” questions. No difference in the mean scores or standard deviations across the three semesters is found. Students answer ~7 of the 12 general questions correctly, and ~13 of the 24 standards questions correctly.

We next examined scores for all of the students responding to the post-test, not matching students across both assessments. Overall, we find that students did better on the post test generally - scores were 26, 22, and 26 (out of 36) for students from the three semesters respectively. The improvement in scores is due to increased correct answers on the LCA standards question set. Students gained ~1 point on the general questions, but 2-4 points on the standards questions. Correspondingly, when looking at the scores for an individual question, we see that students responded correctly more often on the post-assessment than on the pre-assessment. Table 1 shows the percentage of students answering each question correctly. Note that for some questions, students were given the option to “select all that apply” so multiple responses could have been recorded. We give an overall score for that question (100% would mean a student selected only the correct boxes and none of the incorrect boxes), as well as the

scores for the individual elements of a question (the percentage of students identifying one of the options as correct response, or not selecting an incorrect response). Few students were able to get all elements correct as reflected in the overall score, whereas certain elements were easily identified as the correct response.

Table 1. Pre- and Post-Assessment Scores

Question	Pre-assessment percent correct	Post-assessment percent correct
Which of the following are examples of life cycle thinking?	73%	83%
Which of the following are examples of activities of initial costs to be included in a life cycle cost model of a building (you may choose more than one)?	67% (82%, 90%, 46%, 56%)	73% (86%, 89%, 33%, 50%)
Which of the following are part of the LCA standard (choose all that apply)	77% (86%, 73%, 95%, 55%)	94% (100%, 92%, 100%, 83%)
Which of the following activities were done to produce the LCA Standard (choose all that apply)?	53% (56%, 82%, 56%, 33%, 38%)	65% (78%, 94%, 56%, 50%, 47%)
ISO 14040 is an example of which type of standard?	48%	75%
Why is it important to follow a standard when doing environmental comparisons?	88%	100%
Which of the following activities are required as part of the LCA Standard? (choose all that apply)	55% (56%, 87%, 24%, 30%, 76%)	70% (67%, 100%, 58%, 36%, 89%)
Which of the following is not a study design parameter in the LCA Standard	35%	67%
In what order does the LCA Standard suggests dealing with a hypothetical multifunctional system involving a refinery system. Select 1 for the first method, 2 for the second method, and 3 for the third method.	14% (24%, 30%, 14%)	27% (44%, 39%, 53%)
Which of the following is true about input-output models for LCA? (select all that apply)	33% (55%, 56%, 53%)	37% (67%, 58%, 61%)
Why are process matrix models useful in LCA? (Select all that apply)	47% (49%, 81%, 70%, 36%)	58% (72%, 86%, 86%, 44%)
What is true about life cycle impact assessment (LCIA) in the LCA Standard?	39%	47%
How is peer review of an LCA addressed in the ISO Standard? (Select all that apply.)	40% (42%, 73%, 87%)	47% (61%, 86%, 89%)

When looking at scores for students with matched pre-assessment and post-assessment surveys (29 total), we can examine gains more closely. On average, these students increased their scores an average of 4 points or about a 10% increase in score from the pre- to the post-assessment. The majority of those gains came on answering standards questions correctly on the post-assessment. Students in the final semester, who were using the text with additional and updated standards content, increased their scores on the standards based questions more than those in the prior semesters but the difference is not significant.

Student responses to the open ended question - “How would the ISO 14040 standard be useful for completing this LCA task from your boss, if at all?” indicated a gain in awareness of standards in the LCA area. On the pre-assessment, 51% of the students responded “don’t know” or “unsure” or left the question blank. On the post-assessment, no students answered don’t know or unsure, but nine students left the question blank (25%). On the pre-assessment, 30% of students had a response that generally referred to standards, and 13% had responses that indicated some knowledge of LCA. On the post-assessment, 33% had a response that generally referred to standards, and 39% had responses that indicated some knowledge of LCA. These responses included comments about the elements of an LCA that the standard would address, the fact that the standard would promote consistency, and identified the need for using the standard to allow comparisons across different products.

Project Outcomes

The materials added (detailed above) include content on an array of standards knowledge. We emphasize the market orientation of the standards, from both the development and use perspectives. We provide students with linkages from the standard text to the work in LCA that they would be performing or reviewing, thus giving them an integrated view of the role standards will likely have in their future positions in LCA. These areas are consistent with suggested standards content areas [8], [9]. While one chapter of the textbook is specifically focused on the ISO standard, we incorporate references to the standard in subsequent chapters to reinforce the need to be knowledgeable about this content. The students may also have used resources (provided by the faculty instructor or not) that include standards content.

One difference in this approach is the potential reach of the materials. Rather than creating a single module on standards, we created centralized materials in an existing textbook and course materials environment. Within the scope of our project, we had participation from 8 courses reaching approximately 300 - 500 students over the 3 semesters of courses with correspondence about the project that was standards based. We made improvements to the textbook chapter on standards and increased references to standards in other chapters. Outside the scope of the project, we are aware of at least eighty (80) different courses around the world that are using our textbook, with an annual enrollment of around 2,000 - 3,000 students. Since we do an annual update of the text, and notify instructors on our mailing list annually of changes, we have made these instructors more aware of the need to cover standards content in their courses. So, through

this model, we hope to have a far reaching impact on standards awareness among students and faculty alike.

While not assessed via the pre- and post-assessments discussed above, as part of this project we also led the development of a continuing education course provided by the American Society for Civil Engineers (ASCE) on the topic of life cycle sustainability analysis. This course is comprised of about 15 one-hour lecture videos, and a significant portion of one of these lectures relates to the ISO standard and its development. This course, taken by practicing engineers, will further allow the standards content to permeate through additional audiences beyond those of undergraduate and graduate students.

Findings, Lessons Learned, and Potential for Knowledge Transfer

While we did not attempt to extract statistically significant results, we saw an apparent gain in knowledge from the pre-assessments to the post-assessments. These gains could be due to differences in the students' work ethic and success in the individual courses, and selection bias of students who are generally doing well in the class being willing to respond to the post-assessment request. We may also be seeing an indirect effect of awareness on behalf of the faculty member that is extended to the students. Since the faculty instructors were receiving our correspondence about the research project and changes to the textbook in the area of standards, we may be seeing the general effect of these instructors highlighting the standards material in their courses.

Some lessons learned from the assessment project are to provide students several options to complete the post-assessment instrument. The low end-of-semester response rate was disappointing, albeit not surprising. We of course would have preferred a more extensive assessment tool rather than the brief instrument we created in order to get a more robust idea of what the students know at the end of the course. We see some of the questions with low correct response rates that would reflect coverage in course content - for example, few students are able to answer the question about dealing with a multifunctional system through system expansion. Since instructors may not be address system expansion in a course, since it is an advanced topic, the students may not be exposed to this content to be able to answer correctly.

The modest gains that students made reinforce the need for faculty to emphasize standards in the classroom setting. We cannot guarantee that students in these courses, or any courses that use the text, are reading the material to a depth of understanding to have the broad standards awareness that is needed. We hope that by including repeated references to the standard in different portions of the text we begin to address this lack of emphasis.

This work helped to fill a gap in teaching environmental performance assessment by formalizing curricular elements associate with the development of the underlying standards, as well as how those standards enable the comparative assessments of processes, products, and companies. This

will allow many people, beginning at the undergraduate level, to understand the important role that standards have played, and continue to play, in this domain. They will also see how the critical interconnected development of standards and practice are enabling innovative sustainable opportunities to understand and improve environmental performance.

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