Paper 60. A Procedure for Analysing ESD Curricula Applied on Engineering Programmes at Swedish Universities

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Abstract

There are several different methods for implementing curricular elements, but fairly few procedures for determining the success of the implementation. The central question is whether the student has mastered the desired set of skills and the expertise that fulfil the ambitions of the original policy documents. This paper presents a procedure for analyzing how ambitions related to education for sustainable development (ESD) are implemented in educational programmes, i.e. how political ambitions are cascaded down to the level that the student meets in the courses. The method was applied to the programmes in chemical engineering, mechanical engineering and engineering physics at two Swedish universities. The methodological framework is based on analyses of how ambitions on ESD are handled in texts in relevant documents at different levels and the relation between these. The selected texts were: the national degree ordinance, university policy documents, programme curricula, intended course learning outcomes, and learning assessment texts. While the study is focused on the inclusion of sustainable development competences in engineering education, the presented procedure should be general enough for application to any studied aspect of skills in a programme, in particular when this skill is developed in several different courses. The described procedure can also be used to monitor changes over time.

1   Introduction

This study presents a methodological framework for describing and assessing how educational ambitions are handled in relevant policy documents, i.e. how political ambitions are cascaded down to the level that the student meets in courses and in examination. Although the framework is believed to be universally useful, it was here applied to education for sustainable development (ESD) in engineering education (EE) programmes at Swedish universities.

The choice of ESD as the focused field of interest is motivated by the current urgency and importance of sustainable development (SD) in society and the important role of education in general and EE in particular in achieving this. EE has undergone many changes in the last decades (Froyd *et al.*, 2012), where goals for contemporary curricula now often include awareness of social, ecological and economic issues and with increased collaboration with practitional actors in these matters as one of the means.

Traditional EE competences, such as problem solving, communication and entrepreneurship, and typical ESD related competences, such as systems thinking and dealing with ethical dilemmas, all encompass a set of capabilities and are normally addressed in several courses in a programme, which means that they are notoriously difficult to describe and to assess. Therefore, there is a need of tools for analysis of how policies for EE are implemented on a programme level, where different courses together contribute to the end result.

The developed procedure was tested in an analysis of three different EE programmes at two major technical universities in Sweden. The intention was not primarily to compare these different study objects

but rather to provide a rich material for testing the method. The MSc in engineering programmes (five year long) in chemical and mechanical engineering and engineering physics at Chalmers University of Technology (Chalmers) in Gothenburg and the Royal Institute of Technology (KTH) in Stockholm. Only courses that cover at least some aspects of SD were included in the analysis. The in-depth study was limited to the first cycle (bachelor level), as students' normally may choose between different options for their second cycle. Also, the study was limited to courses included in the programme curriculum in the academic year of 2012-2013. Selected texts, relevant for the specific focus on ESD in EE, were: the Swedish national degree ordinance, university level policy documents, programme curricula, intended learning outcomes (ILOs) from course descriptions, and learning assessment texts. The authors of this paper have all been involved in different ways in one or several of the selected programmes and have all been active in course and curriculum development. Most of the authors have worked actively to provide support on ESD. Examples from the described study are used in this paper for illustration of the procedure.

2   Presentation of the framework

The proposed methodology for assessment follows a step-based procedure. The assessment procedure is based on the development and use of criteria for determining how a studied aspect of a programme is described and implemented. Emphasis is placed on how the aspect and different notions of it are visible in documents at different levels relevant for the particular curriculum, i.e. all the way from the policy level (laws and programme policies) to the student learning level (course and examination instructions). The method allows for an analysis not only of how policy ambitions at national level are or are not cascaded down to course level but also for a separate analysis on all levels in order to reveal where new notions of the aspect may appear, although not mentioned in binding policy documents.

Before starting the analysis, the specific context should be selected. The different steps of the procedure are described below, using ESD in EE at Swedish universities as an example.

2.1   Step 1: Deciding on criteria for textual evidence of the studied aspect of an educational programme

In order to judge whether ambitions expressed in policy documents are met in curricula and courses, criteria for what constitutes different levels of textual evidence of the studied aspect needs to be developed. It is an advantage if both weak and strong coupling to the aspect can be mapped. An assessment framework that would focus on only one of these two levels would risk including too much or too little of the content in the analysis. Nuances exhibited by different programmes or different courses in a programme may then be difficult to distinguish. It is also likely desirable for the progression of learning that courses described as having a strong coupling are supported by courses with a weak coupling. For SD in EE, three levels were decided on:

0) *Absence of coupling to SD:* No mentioning of aspects relevant for SD. First semester courses in mathematics typically display no coupling.

1) *Weak coupling to SD:* SD is just mentioned as one topic among many in a list of ILOs or ILOs mention some relevant aspects but without an explicit SD context. In this study, such aspects are referred to as *supporting aspects*; examples are environmental issues, social responsibility, societal consequences, ethics, and global perspectives.

2) *Strong coupling to SD:* ILOs clearly encompass both explicit mentioning of SD, as well as one or several supporting aspects.

2.2   Step 2: Selection and analysis of policy documents at different levels

This step concerns the expression of the studied aspect in policy documents and its transition between different levels, from national level to university or school level. Relevant documents will vary for different settings. At national level, this may include ordinance documents such as laws and governmental policies for ILOs on programme level. At university or school level, there may be both specific local policies that relate to the studied aspect and documents that describe the specific programme.

For ESD in EE in Sweden, the relevant binding document at national level is the degree ordinance for EE. At universities in Sweden, there is typically much freedom and large variation when it comes to local policies and programme descriptions. In addition to the legally binding programme descriptions, universities in Sweden often have vision statements dealing with education in general or with such issues as gender equity, academic integrity, and SD.

The analysis of the selected documents is based on the criteria developed in Step 1. Subsequent steps will depend on the interpretation of how the studied aspect is framed in the policy documents. The procedure for the analysis is:

1. To identify the ILOs (or notions of ILOs) at all policy levels that are relevant for the studied aspect according to the criteria developed in Step 1.
2. To identify similarities and differences in how the studied aspect is expressed at different levels. In particular, the alignment between different levels is of interest.

Once relevant policy documents were available, the time to perform this step varied in the described example from 30 to 60 minutes per engineering degree and university.

2.3   Step 3: Analysis at programme level

In this step, ILOs in programme curricula are matched against the ILOs of the courses in the programme. The procedure is similar to the CDIO procedure of setting up a *programme design matrix* (www.cdio.org), except that it focuses solely on the studied aspect. The analysis is based on the criteria developed in Step 1 and consists of mapping and comparing the ILOs identified in Step 2 to ILOs in the course descriptions. In addition to identifying courses with ILOs that correspond to the studied aspect, the analysis can be extended to cover also progression by use of a relevant knowledge taxonomy. Useful taxonomies are the taxonomies of Bloom (Bloom *et al.*, 1956), Feisel-Schmitz (Feisel, 1986), or the SOLO-taxonomy (Biggs and Tang, 2007), which cover complementary aspects of learning progression.

For this step, curriculum descriptions are needed as well as descriptions of all courses included in each curriculum. Ideally, these texts contain explicit ILOs, otherwise the analysis has to be based on the general text in the documents. The procedure for the analysis is:

1. Identify which courses include ILOs relevant for the studied aspect according to the criteria developed in Step 1.
2. Set up a spread-sheet matrix where relevant ILOs are quoted and categorized with respect to the extent of coupling to the studied aspect.
3. Map and compare the content of the spread-sheet to the ILOs in policy documents identified in Step 2, particularly the ILOs in the programme descriptions.

The time to perform the whole procedure for a single programme (first or second cycle) varied in the example between 20 and 30 minutes, not counting the possibly time-consuming procedure of collecting the course ILOs. An analysis of programmes running over both first and second cycles, as do the Swedish

"civilingenjörsutbildning" (MSc in engineering), is potentially more time-consuming as many of these programmes offer a multitude of choices for the second cycle.

2.4   Step 4: Analysis at course level

In this step, the assessment of learning in a course, e.g. the questions that the students have to answer at a written exam or the tasks required to pass the course, is analysed in relation to the ILOs of the course. In other words, this is an analysis of whether or not a course is *constructively aligned* (Biggs and Tang, 2007), or at least how well the assessment is aligned to the ILOs (as teaching and learning activities are not analysed in the suggested procedure).

This step requires the ILOs of the courses as well as descriptions of the forms and requirements of the assessment, including the actual material for the assessment of learning in the course, including projects, hand-ins, seminars, written exams etc. The procedure for the analysis is:

1. Systematically go through and analyse all parts of the assessment, i.e. each question in the written exam as well as all other mandatory tasks.
2. Identify how large part of the assessment that is aligned to which ILO (relevant ILOs for the course were identified in Step 3).

The time to perform the procedure varied in the example between 15 to 30 minutes for a course.

3   Examples of results for EESD at Swedish universities

3.1   Step 2: Selection and analysis of policy documents at different levels

The national degree ordinance in the Swedish university law for the "civilingenjörsutbildning" (MSc in engineering) presents two specific ILOs with strong SD orientation, see Table 3.1. These national level ILOs are articulations of SD on the highest and most abstract level. The expectation is that these ILOs are locally translated or adapted to the specific educational programme and become operationalized in further detail on the lower levels in the education chain.

Table 3.1: National level ILOs in the national degree ordinance for "civilingenjörsutbildning" (MSc in engineering) that have a coupling to SD (Authors' translation).

"The graduate shall:
- show capacity to develop and design products, processes and systems with consideration to human conditions and needs and to society's goals for economic, social and ecological SD;
- show understanding of the possibilities and limitations of technology, its role in society, and human responsibility for its use, encompassing social and economic aspects, together with environmental and work condition aspects"

Both Chalmers and KTH present general vision statements regarding implementation of SD, but without explicit guidelines for programme directors or teachers. The Step 2 analysis showed that the alignment between national policy documents and university vision statements, at both universities, is missing or exists only in an implicit manner.

National level ILOs are in Sweden binding for the programme curricula. The goals on national level are to some extent found in verbatim usage in the ILOs for the selected programmes of the study. For example, the chemical and engineering physics programme curricula at KTH show no adaptation or further operationalization of the national level goals. At Chalmers, the programme ILOs for the three

programmes are all more locally adapted, while verbatim text passages from the national level are found in the ILO for the chemical engineering programme. For both universities, the mechanical engineering programmes show ILOs at programme level that differ from the national level ILOs and where some degree of further operationalization has taken place. Table 3.2 shows how the national programme ILOs of Table 3.1 have been adapted to the specific demands of the Mechanical engineering programme at Chalmers.

Table 3.2: Example of local adaptation of national level ILOs that have a coupling to SD (Enelund *et al.*, 2012).

The Master of Science in Mechanical Engineering graduate shall be able to:
3 Lead and participate in the development of new products and systems with a holistic view to stating requirements and formulating concepts, to design, to manufacturing, and through operation to decommissioning, following a systematic development process adapted for the current situation. This includes being able to:
3.4   Select materials with an understanding of how such choices affect the manufacturing process, product behavior and environmental impact during the life cycle of the product
3.5   Compare and evaluate different product solutions with respect to function, environmental impact, production and cost
3.6   Analyze, design and select production systems and machining processes with consideration to efficiency, work motivation, safety and work environment
3.7   Describe and estimate the economic, societal and environmental consequences of a product or system through its lifecycle
7 Understand and estimate how human behavior affects the earth's climate and ecosystems
8 Identify the available energy resources (renewable and non-renewable) and explain how these can be transformed to other energy forms, along with their limitations and environmental impact

3.2   Step 3: Analysis at programme level

The in-depth study of the implementation of programme goals in courses is limited to the first cycle (bachelor level), as students' may choose between a large number of options for their second cycle. Only compulsory courses covering ILOs marked as concerning environment and sustainable development (E&SD) have been analysed. At Chalmers, programme directors decide which courses that treat aspects of E&SD in their programmes. At KTH, courses identified to deal with environment, environmental technology or SD are marked by KTH-S (the KTH Sustainability Council), which is an advisory body to the President of KTH. Also, the study was limited to courses included in the programme curriculum in the academic year 2012-2013.

Among the ILOs of all the analysed courses there are a total of 41 course ILOs with a coupling to SD, according to the criteria decided upon in Step 1. Of these, only 8 have a strong coupling to SD while the majority of the ILOs have a weak coupling to SD. Also, one course was found to lack ILOs for SD altogether despite being marked as an SD course, an obvious example of what can be discovered using the present methodology. Considering that implementation of E&SD is an on-going process, one should not be surprised to find such omissions – by identifying such oversights, relevant ILOs for SD can be added to the course description and the course be further developed.

By mapping and comparing the course ILOs to the programme ILOs, it is possible to evaluate whether the student is likely to acquire the ILOs for SD. Also, it is possible to identify and follow the progression of ILOs for SD throughout a programme. As an example, the E&SD courses at the Chemical engineering programme at Chalmers are listed in Table 3.3, together with examples of identified course ILOs that have a coupling to SD, and an indication of the intended learning progression for SD. The ILOs that are

marked with grey in Table 3.3 indicate a progression through the Chemical engineering programme at Chalmers with respect to the intended level of depth (or complexity) of learning. In this case, the intended learning starts with the ability to describe and identify, followed by the ability to estimate and assess, and finally the ability to critically review and evaluate (Svanström & Lundqvist, 2012).

Table 3.3: Examples of ILOs that have a coupling to SD in subsequent courses at the Chemical engineering programme at Chalmers. The ILOs that have a strong coupling to SD are marked in bold style. An example of an identified learning sequence is marked with grey background.

Chemical engineering, environment and society	Heat and power technology	Chemical environmental science	Products and processes in a sustainable society
1. describe the most important environmental problems connected to chemical industry, concerning emissions and waste as well as products and resource use **2. describe a specific chemical engineering process and explain important sustainability aspects for the process** **3. identify important sustainability aspects for different chemical engineering processes**	1. describe orders of magnitude, trends and environmental aspects of energy supply and use, nationally and globally 2. estimate environmental consequences of large scale combustion 3. describe technical measures to reduce environmental impacts associated with combustion	1. describe the chemical and physical mechanisms behind regional and global environmental effects 2. explain the necessary conditions for human life regarding ecological processes and natural cycles 3. assess environmental and health risks in use, transfer and chemical conversion of hydrocarbons, chlorinated hydrocarbons and other substances 4. describe relevant work on environmental goals and relevant environmental policy instruments, nationally as well as within the EU	1. have gained good familiarity with calculation methods for process efficiency (material, energy and economy). In this is included to be able to utilize flowsheeting software for estimates of process data and to be able to perform simple life cycle assessments. **2. critically review and evaluate sustainability aspects and environmental impacts of processes and products** 3. good insight into systems for environmental management within companies and how this is integrated into the operation of companies

3.3   Step 4: Analysis at course level

This is an example of how to estimate how large a part of the course assessment is aligned with the ILOs for SD. The example is taken from a thermodynamics course in Engineering Physics at KTH, see Table 3.4. The course has four comprehensive ILOs, one of which has an SD coupling. The course consists of three modules, examined and assessed separately: a written exam, a laboration, and a small project. The questions on the written exam were compared to the SD-coupled ILO. The points for each exam question reflecting the SD-ILO was divided with the total points for the exam. The procedure was repeated for several successive written exams in order to find an average over time. The examinations and assessments for the laboration and the project were also compared to the SD-ILO. These estimates of how large a part of the examination deals with SD were then compared to the information in the course description. In this example, one of four ILOs addresses SD issues, and one quarter of the assessment deals with SD, indicating that this aspect of alignment may be good. Further analysis of the teaching and learning activities in the course are, however, necessary in order to evaluate the constructive alignment. The

outcomes for other courses show that some ILOs are covered only to a small extent, or sometimes not at all, by the assessment, while other ILOs are covered to a large extent.

Table 3.4: The figures show how large a part [%] of the assessment in a thermodynamics course in Engineering Physics at KTH that is aligned with ILOs with an SD coupling.

Course module	Written exam 4 ECTS	Lab 1 ECTS	Project 1ECTS	Full course 6 ECTS
Part [%] of module	14.6	0	100	–
Part [%] of full course	9.7	0	16.7	26.3

4   Discussion and conclusions

The presented methodology is a useful tool for monitoring the implementation of any studied aspect of intended learning outcomes. By checking the consistency of policy documents, from governmental decrees to course assessments, it is possible to study whether high-level ambitions are cascaded down through the educational system to the level where students' learning is assessed. However, it is not enough that an analysis shows the relevant policy documents to be consistent throughout the chain. The analysis is the starting point for a more thorough investigation of what is actually done on course level.

The development of criteria in *Step 1* for assessing the implementation of the studied aspect, in this case SD, makes for a robust foundation for analysing the studied aspect at different levels. The selection of criteria must, however, be tested for content coherence. A calibration among the authors of the criteria used was required in order to reach consensus.

For *the second step,* it is important to identify all national and university level documents determining ILOs for SD. It is also important to assess the status of the policies found in order to determine their connection to programme and course descriptions. In Sweden, the national level programme descriptions are legally binding and are used as starting points for the locally adapted programme descriptions. The extent of adaptation of the general ILOs at national level to the specific circumstances of the local programme ILOs varies from use of verbatim text passages from the national ordinance to thorough reworkings of the local ILOs, adapted to the programme in question. This means that operationalization of SD in ILOs differs significantly at the programme level, which may present difficulties in comparing programme goals and course relations. The general university level vision statements for SD, by contrast, show none or little connection with either ILOs at national level, or local programme ILOs.

The outcome of *Step 3* is a mapping of which courses that include ILOs for the studied aspect, in this case E&SD. By including the full text of the relevant ILOs into the design matrix for the studied aspect – rather than merely noting presence or absence of ILOs – a full overview for the aspect is created. Programme ILOs that are seemingly not addressed anywhere in the courses can be readily identified. Ideally, the analysis should encompass all courses in a programme, not merely those that happen to be marked as of interest. The consequences of the outcome may vary from a need to update university policy documents so that actual practice is reflected, to an indication of a lack of follow up of some high level ILO. The inclusion of the full text for the ILOs for the studied aspect also allows for a monitoring of learning progression throughout the programme, as seen in Table 3.3. While *Step 3* checks whether all high level outcomes are addressed on the course level, further inquiry is necessary to answer the question if the assessment and teaching and learning activities are appropriate. For SD in the courses investigated, all marked as covering aspects of E&SD, examples of omission of ILOs for SD were found, as well as examples of learning progression.

Step 4 addresses the question whether the ILOs are assessed, and to what extent they are assessed. It is usually quite straightforward to analyse written exams with respect to how much of the assessment focuses on a studied aspect. For most other forms of assessment it is harder to estimate how large a part of the assessment that is aligned with a particular set of ILOs. Indeed, it is not necessarily clear how much of a course that is intended to deal with an ILO, especially not for courses where the teaching-learning activities and assessments of an ILO have been integrated into the overall fabric of the course. In many cases it is necessary to acquire additional information and clarifications from the responsible academic staff. It is also recommended to check the preliminary results of the analysis with the responsible staff, to ensure that the alignment between the ILOs and the different parts of the assessment has been correctly understood. The results from the analysis in *Step 4* can give useful information for course development, *e.g.* when it turns out that some ILOs are covered only to a small extent, or not at all, by the assessment.

The presented methodology should be useful for monitoring the alignment of ILOs between different levels, as well as intended learning progressions throughout a programme. Once an analysis has been made, it should be easy to monitor changes over time. The methodology should be general enough to identify issues that need to be addressed, regardless of which particular aspect or which programme is studied. A complete and consistent chain of policy documents covering a studied aspect does not of itself guarantee that the ILOs are dealt appropriately with in teaching-learning activities and assessments. Nor do omissions of ILOs, or discrepancies between different level ILOs, constitute sufficient evidence that a subject is *not* covered appropriately, somewhere in a programme.

The presented methodology is likely of greatest use for programme directors and such functions where there is a need for monitoring the outcomes of curriculum design. Any necessary changes in course ILOs need to be treated in dialogue between the programme director and the course responsible teachers. The necessary changes can vary from an updating of programme or course ILOs ensuring alignment with the national level to the development of courses, course modules or even teaching and learning activities. For instance, the highly complex ILOs necessary for engineers to master in the field of E&SD are unlikely to be adequately assessed in written exams.

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