How to Teach Systems in Engineering Education: The Case of an Energy Systems Course

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ABSTRACT

Purpose: To design an energy systems course, which should fit into an energy studies master program curriculum and build on students’ earlier gained knowledge put into a systems context.

Design/Methodology: The course was based on a number of assignments, which were to be carried out in groups of three students and which should provide simultaneously learning about particular tools and the systems dimensions.

Findings: The applied learning concept generally worked well, but many students could not see the value of reusing old knowledge in new contexts; found it difficult to use several different types of software with the learning purpose of the ability to choose software rather than to learn the details of one already chosen by the teacher; and wanted well-defined texts for the exam rather than apply the knowledge and competencies gained during the assignments. The concept of mixing students with varying energy cultural backgrounds worked well.

Conclusions: Assignment-based courses work well for teaching systems but there are some constraints, which should be considered.

Practical implications: Since a large number of students may find it confusing to be simultaneously introduced to a partly new subject and to apply unconventional teaching methods, there might be trade-offs with regard to the systems learning and teachers should be aware of that.

Value: The main value of the paper is that is shows one way of integrating systems learning into the structure of a course.

Keywords: *energy systems course, assignment based, group work, open-ended issues*

INTRODUCTION

Engineering education is still largely fragmented, and courses are mainly traditionally based on an approach where the technology itself is in focus, and only rarely questions are raised how this fit into a broader context. This is often claimed to be a major problem of engineering education and the engineers educated.

The basis of systems science is to put parts and pieces into a broader context, and thus the systems approach is very different from that applied in traditional engineering education. The question is then how to combine the two approaches in a smart way, or how systems can be effectively taught based on the students’ technological knowledge and how the engineering students’ technical competencies may be integrated into the broader context.

Despite the urgency of environmental and climate issues, the tight coupling of climate issues in particular, as well as most other environmental issues – how we use energy, and the importance of engineers and engineering education in this respect – it is surprising how scarce the literature on how to teach energy systems in engineering education is. This is point of departure of this study.

PURPOSE

The purpose of the study is simply to address, by using a concrete case, how systems aspects can constitute the basic concepts of an energy systems course in a way that not only makes students understand the issues but also makes them learn how to work with them, and to assess if the chosen approach is working well.

There are some constraints to the case since the developed course should fit into a master program curriculum at a technical university (Chalmers), and a number of system tools should be included in the course.

METHODOLOGY

This paper presents the development of a course in energy systems denoted *Energy Systems Modelling and Planning*. The course was then given once annually during 2008-2011.

The assessment of whether the chosen course approach were successful or not with regards to the students’ learning of the systems aspect is based upon the students´ course evaluations. Each year during the 2008-2011 period, the course was evaluated by the students after the exam. During the final three years this was done more systematically using the new Chalmers course evaluation scheme. That is to say, it was a written evaluation based on a standard set-up of questions as provided by the university, which was complemented by questions specifically related to the chosen course concept (assignment- and group-work based, and including open-ended issues, student peer-review etc., as presented in detail below) with questions attempting to address both the students´ learning outcomes and the liking of the concepts. Each year after the end of the course, there was a course evaluation meeting with two or more course representatives. At the meeting there was agreement on some issues that should be improved or modified until the next time the course was to be given.

BACKGROUND

Chalmers Technical University decided on an increased adherence to the Bologna process by making a clear division between the bachelor and master levels. This implied that the students in the different five-year engineering programmes during their last bachelor year should choose a master programme (and that all courses at master level should belong to a master programme), and that the teaching language change from Swedish to English when starting at the master level. Some master programmes were already running at that time at the university, while others had to be developed. Some courses of the master programmes were specific to a particular programme while others were shared between different programmes.

The Sustainable Energy Systems (SES) programme was developed as a specialisation aimed at students from the Mechanical, Chemical or Chemistry with Physics Engineering programmes. Some of the courses included in the SES programme curriculum already existed as parts of other master programmes, notably the Industrial Ecology programme, while others were taught in Swedish as final year specialisation courses of the Mechanical or Chemical Engineering programmes but needed to be translated into English and, to varying degrees, modified to fit into the master programme curriculum.

The *Energy Systems Modelling and Planning* course was scheduled as the last compulsory course of the SES master programme, and since it should fit into the master programme curriculum it was necessary to consider both what students in the programme so far had learned, and what further competences they needed to gain in order to be prepared for the master thesis. This had to be taken into account when designing and developing the course.

Further, the course should be designed for on average 60 students (Swedish and international) annually with varying educational backgrounds.

The aim of the course was to give the students insight into the complexity of energy systems and to provide them with practical tools to solve energy system analytical problems. The aim when developing the course was to use real problems, to create an engineering-like (and thesis-like) situation through building on knowledge and competencies that the students had already gained in other courses rather than provide a lot of new facts, and to ask the students to solve a number of real-world interdisciplinary problems by combining previously gained competencies and knowledge.

Further, integration was considered to be a central aspect of the course. The ambition was also, as real problems, to combine and integrate technical, environmental and economical perspectives. The course should focus on local, regional and national energy systems rather than global systems, which were already covered in a course most of the students had already passed (the Energy Systems Futures course given earlier in the programme). In that course, primarily lecture-based, the students should have learned general systems thinking applied to energy and a toolbox for energy systems analysis. Finally, the application of *reference energy systems*, *load curves* and *environmental policy instruments* was decided as central competencies that the students ought to learn, and thus should be central in the course since the students had not gained sufficient insights from earlier courses into these concepts, which are very useful for many energy engineers.

Learning goals were first to be formulated. Then some major decisions about the course design should be made. A key question was if the traditional lecture-based course with a few exercises and assignments added would be able to teach the students how to work with systems, or if a less traditional course based on assignments as the backbone of the course, with only limited reading material provided and only a few lectures intended to provide the students with basic concepts and theories, would be better suited. The latter path was chosen. The following presents how the course was developed, then follows a section on the choice of pedagogical concepts and assessment methods, a section on the students’ course evaluations, and, finally, a concluding discussion.

KEY DEVELOPMENT ISSUES

First the **learning goals** of the course were formulated. These were formulated as (hardly modified during the first fours years of the course): *after completion of the course, students should be able to:*

- *analyse energy systems using simulation and optimisation modelling tools;*
- *construct and use load duration curves based on chronological load data;*
- *select and define appropriate reference energy systems;*
- *apply system analytical tools;*
- *understand the interaction between energy conversion technology, environmental impact and economic performance;*
- *understand the interaction between different parts of the energy system;*
- *understand how energy policy instruments affect energy system investment decisions;*
- *apply systems thinking to energy problems;*
- *understand marginal effects;*
- *define and calculate the overall efficiency of a given energy system.*

Further, the idea was not to cover the various learning goals one by one in the different parts of the course, but rather that the learning goals should be part of the various course elements and thus form the backbone of the course. In this way, each of the goals is dealt with during several course sessions with the aim of enhancing the learning of the goals.

It was decided that the course should be based on six assignments. Five of the assignments were covered in a sequential order providing progression, while the sixth one ran in parallel with the others. The assignments were developed as not only providing learning goals, as presented above, but also in order to address the fact that students from different countries have very different relationships to energy issues depending on factors like climate, current energy system, resources, per capita energy use etc; this is what we denoted as different *energy-cultural backgrounds*. This required considerable attention due to the use of very Swedish cases and examples (like district heating). The solution was both to add non-Swedish examples and to prove that the learning outcome was much more general than what was immediately apparent.

It was believed, with students from all over the world, to be important that students recognise themselves in different types of examples, and feel that the selected examples are as much about the work they are going to undertake in their respective home countries as about specifically Swedish conditions. This contributes greatly not only to the assured quality of the course but is also essential since in order for the work-integrated learning to work for all students, the students' diversity of experience must be utilised, especially since the course is based on extensive student participation.

There were several criteria for the cases to be chosen. They should obviously fit well into the course structure, but they should also contribute something qualitatively new and improve student learning. Since the course is based on only a small amount of new theory and since the course's main objective is the application of theory from various previous courses to a number of more extensive cases, the students should be able relatively quickly to grasp the technological dimension of the cases. There was also the intention to include a certain degree of openness in that student groups themselves should define cases, and justify why they chose these particular issues. A final criterion for the selection of examples was that they should be based on, or include, the use of computer-based energy models of a different type than the models already used in the course.

The six assignments chosen to deal with are as follows:

- *Assignment 1 Energy systems – An assignment based on a newspaper debate on the environmental benefits of district heating. The students should take part in a debate and formulate their standpoints and their justifications.*
- *Assignment 2 RES – Reference energy systems (RES) are a key tool in energy systems modelling and the students should learn to create a simple RES based on detailed instruction and to use the concept of load diagrams.*
- *Assignment 3 Biogas – An open assignment where the students should choose a biogas system of their choice, and formulate relevant system boundaries, key environmental issues and make some simple calculations based on this.*
- *Assignment 4 MARTES - A computer-based exercise using the simulating MARTES model including analysis of district heat production. Investment alternatives were to be evaluated from economic and environmental perspectives.*
- *Assignment 5 LEAP - A computer-based exercise using the LEAP model. LEAP (the Long range Energy Alternatives Planning system) is an integrated energy-environment modelling tool. Its methodology is based on a comprehensive accounting of how energy is consumed, converted and produced in a given region or economy.*
- *Assignment 6 LP - A simple linear programming model is to be constructed for cost optimisation of a district heating system The model should be constructed in Excel. The optimisation is carried out taking into account environmental considerations and possibilities for investment in new* technologies.

Assignments 4, 5 and 6 are computer-based assignments, 4 and 5 using simulating models and 6 using a linear-programming optimising model. The modelling tools utilised are models being used frequently by professional energy system modellers as decision support tools. A challenge with regards to the learning of modelling methodology was that the intention as formulated in the learning goals and further developed during the lectures was to learn the modelling methodology and the specific models' possible application areas, strength and weaknesses rather than learning the different softwares in detail. This is further discussed below.

Assignment 1 and 2 should be solved individually while the others should be solved in groups of three students, and each student group should write an assignment report. Assignments 3-6 were context rich and, in line with Heller, Keith, & Anderson (1992), context-rich problems are very well suited for group learning since the group efforts enhance the learning. In addition, since the students had different study backgrounds (primarily mechanical and chemical engineering), and also different cultural backgrounds (from a number of European countries but also a number of students from Asia, and some from other continents), a forced grouping could further add to the learning by group-solving of the assignments. Then, not only their different study backgrounds but also their different countries of origin could benefit the other group members rather than being an obstacle, since it could provide fellow students with insights into energy and environmental issues in other countries than the students' home country. For this reason it was decided to apply forced grouping. This was also necessary since in each group it was necessary that there was at least one student fluent in Swedish since the interface of one of the computer models used was in Swedish (and translation was too costly).

The Assignment 3 Biogas ran in parallel with the other assignments. The assignment was open-ended (see, for example, Daniels, Cajander, Pears, & Clear, 2010), and the students received only a brief introduction and then had to choose a case and formulate a relevant question related to the production, distribution and use of biogas, and then to solve the assignment taking into account technical, economical and environmental aspects. The highly open character is further discussed below. It has turned out that many of the students appreciated this design, but it was also highly criticised. Biogas has recently been addressed as an ideal example for "teaching sustainability across scale and culture" (Barnhart, 2012), much along the lines of the ideas behind the Assignment 3 Biogas.

PEDAGOGICAL CONCEPTS AND ASSESSMENT METHODS

So far we have addressed some pedagogical ideas that formed the backbone of the course such as:

- The course should be based on assignments rather than lectures;
- It should provide learning in a programme perspective where the major theory already had been covered in lectures but the students should apply it (and combine with elements from other courses);
- Learning of modelling methodology rather than learning the different softwares;
- Group work;
- Case studies in a global context where all students, despite their background, should have the impression that the learning is useful despite being primarily based on Swedish cases.

In addition, the course development also introduced a number of pedagogical ideas and learning concepts. These were:

- Constructive alignment (Biggs 1996),
- Self-assessment of reports,
- Presentations of group work,
- Opposition to other groups presentations,
- Open ended questions and assignments.

Peer assessment, where other student groups assess fellow students´ reports, had dual objectives: both to concentrate teacher resources where they are most needed (due to university economic constraints), but also to develop the critical thinking the students need when they start their master thesis.

In summary, the course was based on a number of compulsory assignments, of which the majority should be carried out as group exercises. The lecture and course reading were mainly aimed at providing a background to the assignments. The course also included a number of pedagogical methods and concepts of which some were less familiar to most students taking the course.

The course was examined by approved assignments and a written exam. The first assignment was intended merely as an introductory exercise and did not need approval. The second assignment was to be solved individually, while the remaining four assignments were to be carried out in groups of three who delivered a common report, which was assessed. The written exam was individual. Thus, the assessment was a combination of group and individual assessments.

STUDENTS' COURSE EVALUATION

The outcome of the students´ assessment of the course changed, and became slightly more positive during the years 2008-2011, while a main characteristic of the students' assessment remained: the students seemed to be fall into two categories, one group who strongly disliked the course and one group who rather liked it.

One point that was frequently criticised by a number of the students (probably those who gave the course generally not very good reviews) in the students' course evaluations was that the course was not providing any new knowledge but rather was "reusing stuff" from other courses. This indicates that many final year students do not realise that new knowledge can be obtained by combining previously gained knowledge in various ways, which is rather problematic. Since this was part of the core course concept and provided essential learning, this could not really be changed. As mentioned, many students appreciated this concept.

While some students gave the course high, or even very high, scores, there were also a number of students who were far from satisfied with the course. An analysis of the students´ course evaluation shows that the students were generally satisfied with the assignments and the learning they provided, and that the satisfaction with assignments seemed to be far greater that the satisfaction with the course, despite the course being not so much more than the assignments put together in a progression. This resulted in a very difficult task, since it is far from clear how the learning outcome may be improved based on the students´course evaluations without eliminating some of the basic course learning concepts.

In the first year that the course was offered, 2008, there were a number of initial problems mainly related to the course structure, and how all the assignments should fit in (not the least of which were practical issues with regard to how suitable classrooms could be arranged). The students also criticised the fact that they received their feedback late on some of their assignments. These issues were corrected during the following years and the students´ general assessment of the course improved as a result.

Another student criticism was that there were too many assignments, modelling methods and different softwares used so there was no time to learn the different methods and software in sufficient depth. However, here also the criticism was actually targeting one of the learning goals of the course: that the students should learn to be able to select an appropriate method dependent on the problem situation they are in, rather than learn how to use one or two selected methods/software in depth. Thus, this criticism from a number of students did not lead to any change in the course. Again, this course design feature was appreciated by a number of students.

The open-ended assignment on techno-environmental assessment of biogas (which one student during the 2011 course claimed to be the very best and most meaningful part of his entire education) was generally strongly criticised. The assignment outline was improved from year to year by adding clarifications and some constraints and limitations as requested by the students, but it did not help much.

Since open-ended issues are a part of the course, this was also reflected in the exam. However, these open-ended exam questions greatly confused many of the students, and thus these were also decreased to a minimum. It can also be argued that the exam situation as such is not well suited for open-ended issues since the students are nervous and open-ended issues add to the nervousness.

The group work generally had good reviews and the forced grouping also received a positive evaluation.

Finally, the feared view from the international students, that the course focused too much on the Swedish example and systems, seemed not to be an issue judging from the evaluation results.

CONCLUDING DISCUSSION

Integration of different aspects of energy, environment and sustainability are difficult to teach in traditional lecture-based teaching, and students’ learning is improved by using problem-based learning focussing on different case studies in accordance with the findings by Segalàs, Ferrer-Balas, & Mulder (2010) and Mulder, Segalàs, & Ferrer-Balas (2012), who conclude that the learning of sustainable development is enhanced by the use of case studies and problem-based methods.

In the above presentation of the students´ evaluation of the *Energy Systems Modelling and Planning* course, I concluded that some aspects, which are central to the learning concept of the course, received fierce student criticism. In particular this concerned the open-ended issues and the system-based learning focus on the combination of competencies from previous courses without too many new facts provided (in particularly in lectures), both essential from a sustainability/systems perspective. The same two areas were highlighted in a recent Chalmers´science alumni review (Review Science, 2011) as missing in the curricula.

During the three first years of an engineering education, there is probably not a great need for the introduction of open-ended issues, and it has further been shown that constructivist and problem-based approaches work only when students have gained sufficient skills and competencies to be able to provide “internal guidance” (e.g. Kirschner, Sweller, & Clark, 2006). However, a central part of the engineering profession is not only to answer predefined questions but also to ask questions and, particularly, to ask relevant questions. Open-ended issues as part of the curriculum are thus one way of introducing learning towards the ability of asking relevant questions and, thus, the use of open-ended issues/assignment is highly important for engineering students in particular when addressing sustainability. Difficulties with open-ended issues in general, including the students general dislike of these, has been discussed by Daniels et al. (2010).

The way of assessing group-based courses has been dealt with in the literature (e.g. Hellström, Nilsson, & Olsson, 2009; Helle, Tynjälä, & Olkinuora, 2006). This was not really an issue for the present development since it was decided at an early stage to apply a combination of group assessment of the assignment reports and individual assignments through a written exam.

The strikingly clear division of the students in two major groups with regards to their general appreciation of the course was puzzling. In discussion with the few other teachers who gave courses based on a similar pedagogic concept (in other subjects), it became clear that they had also noticed that the evaluation of courses focussing on the combination and application of concepts and competencies gained in previous courses rather than providing new facts seemed to reflect two student categories, one in favour of the concept and the other disliking it.

The study cannot conclude that the applied assignment-based approach is necessary for students' systems learning since we do not have any reference. However, it was clear from the students' evaluation that the more traditional assignment (except Assignment 1, based on a newspaper debate, and Assignment 3, the open-ended assignment), based on calculations and computer programs, were much appreciated, which may be seen as proof of providing learning in a good way.

The parts of the course which were based on untraditional pedagogies and methods were generally not well received by the students and in some instances received fierce criticism from many students (but far from all).

After three years of running the course, the students were asked if their main interest lay within the area of energy technology or within energy systems. About half of the students chose either option. It is likely, and some evidence for this was gathered during the final end-of-the-course discussions, that half of the students who had their main interests within energy technology also were the students most critical of the course.

While it cannot be proved from the study, it is likely that the application of a large number of new pedagogical concepts in one course not only is really a challenge but also that it might lead to confusion for students (or at least the large group of students at engineering universities who are very fond of tightly structured courses without too many surprises). This, in turn, reflects probably negatively on the systems learning itself.

Using students´evaluation of the course as the bases for an evaluation of the learning has certain disadvantages. To like the course is not necessarily the same as the successful attainment of learning goals . However, the learning systems aspects are inherently difficult to assess since they are multi-dimensional. To have had as reference students undergoing traditional lecture-based education in parallel would have ideal, but this was not possible.

Finally, systems studies is about combining various parts into something which is greater than the sum of the parts, and the combination and "reuse of old stuff" must be central in any systems course; and sustainability requires the ability by decision makers, and engineers, to formulate relevant questions, and not only to provide answers to already formulated questions. The consequence of this is that the engineering education of sustainable energy systems should include a variety of teaching methods.

Take home messages

- A project-based approach works well for teaching energy systems.
- Forced grouping of students with varying energy-cultural backgrounds adds to the learning.
- Since the approach might be new and, thus, somewhat uncomfortable to many students, it is important not to make the course too complex with regards to structure and pedagogical tools.
- A project-based energy systems course is a good preparation for student´s thesis project.

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