FUSING PROGRAMMING AND THERMODYNAMICS IN A FIRST YEAR ENGINEERING COURSE

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ABSTRACT

This paper describes a first-year undergraduate engineering course called Energy that has been developed and taught at the Department of Engineering at Reykjavik University. The aim of this course was to merge Matlab programming and thermodynamics into one course. In this course the students learn the fundamentals of thermodynamics and solve thermodynamic and energy related assignments using Matlab programming. Other courses that the first-year students are taking simultaneously also integrate Matlab into their curriculum to some degree. In the 2020 course the syllabus of Matlab programming and thermodynamics was fused together from day one, with many students having difficulty in learning the basic programming while taking in new theoretical relations of thermodynamics. This was changed in the 2021 course where the first 4 weeks of the course focused almost entirely on Matlab programming and the remaining 8 weeks focused on thermodynamics, where Matlab was used as a tool to solve problems. In 2022 this was split into two courses, one 4 weeks Matlab course and one 8 weeks Energy course where students continue to use Matlab. The course is being developed further, but the main feedback from students is that they prefer the content of programming and thermodynamics to be distinguished to some extent. Developing this course is in line with the CDIO standards 3 and 4; Integrated curriculum and Introduction to engineering where students get real data to work with which relates them more to modern and current engineering challenges in energy related topics. This will prepare them for working on the energy challenges the world is now facing.

KEYWORDS

Curriculum Change and Curriculum Agility, Sustainability in Engineering Education,
Standards: 3, 4

INTRODUCTION

Undergraduate study in engineering at the Department of Engineering (DE) at Reykjavik University (RU) in Iceland aims at providing solid background for specialization in different engineering study lines and prepare students for graduate study and engineering profession. Annually around 200 students are enrolled into the first year of the following BSc programs: Financial Engineering, Engineering Management, Biomedical Engineering, Mechatronics, Energy Engineering, Mechanical Engineering and Electric Power Engineering. DE at RU has been implementing the CDIO approach into its curriculum for more than a decade (Audunsson et al. (2020) and Saemundsdottir et al. (2012)

Programming is an essential factor in the engineering curriculum and it has been a core subject in undergraduate studies of all engineering study lines taught at RU. The students who are enrolled into the engineering programs come from different secondary schools and many of them have little or no experience in programming while other students have graduated from specific computer science programs. To get the students to a similar page when it comes to programming, Matlab programming has been used as the first programming language they learn at RU and it has been taught in a specific Matlab course. Matlab is considered to be a relatively simple and a user-friendly syntax which works well for engineering students with little or no background in programming, and it has been widely taught in engineering curriculum (Bettin et. al, 2022). At RU a 6 ECTS course in Matlab programming has been taught for first year engineering students since year 2009 and after completing that course students have taken another 6 ECTS course in a computer language like C++ or Python. Earlier this was considered to be a successful setup but in recent years, students are more frequently using Python instead of Matlab in other courses and thesis work in later years of their studies. That fact has shifted the emphasis from a whole 6 ECTS course in Matlab programming into learning only the basics of Matlab programming and integrating these skills into other courses. This has been successfully integrated in many other programs at technical universities, an example of a CDIO approach to this can be found in a paper by Enelund et al. (2011).

In Iceland, almost all of the electricity is produced from renewable energy sources like geothermal and hydropower (Energy Statistics, 2022). The country has a unique opportunity to phase out fossil fuels in their transportation sector. The current energy transition aims at replacing fossil fuels with renewable energy, either using electricity directly or by producing E-fuels (e.g. hydrogen and ammonia) as energy carriers. Iceland aims for carbon neutrality by 2040 (Gov. of Iceland, 2020) and the energy and transport sector will be one of the biggest contributors to fulfill that goal. It is therefore important that all engineering students in Icelandic universities get a solid background in thermodynamics and knowledge of the energy sources, since it is likely that they will be required to have these basic skills in their future employment, regardless of which engineering study line they have selected. This subject is also an excellent platform in a university course to integrate with the basics of programming to perform calculations, import data and present results e.g. in spreadsheets and graphs. This outlines the motivation for the development of the new first year course in undergraduate engineering studies at RU that is described in this paper.

The aim of this paper is to describe the development of the new course Energy at RU which has been in the engineering curriculum since 2020 and how the lessons learned have led to changes in that course over the past 3 years this course has been taught. During the course development the CDIO Standard 3 for Integrated curriculum as well as Standard 4 of Introduction to engineering (CDIO, 2023) have been implemented.

THE ENERGY COURSE

Background

In 2019 when a new Dean of Department of Engineering and a new Department Council came on board at RU, they decided to do curriculum changes to the study lines offered at the department. For the study lines Financial engineering and Engineering management two courses; Chemistry (6 ECTS) and Thermodynamics (6 ECTS) were removed as mandatory courses. Also, all students now take a course in Python programming in the second semester. This initiated changes to how programming and thermodynamic courses were taught for the first-year undergraduate students.

It is very important that all engineers have fundamental understanding of thermodynamic processes and how energy conversion takes place and which limitations apply according to the laws of thermodynamics. In particular, basic practical knowledge of thermodynamics and energy technology is of special importance in Iceland due to the current energy transition. Therefore, since some study lines do not have thermodynamics as a mandatory course anymore and students learn programming in Python already in second semester, it was decided to merge introductory thermodynamics and energy technology together with practical programming in Matlab into one course, called Energy. It is to be noted, that some study lines (e.g. Mechanical and Energy engineering) still have mandatory courses in Chemistry and Thermodynamics later in their curriculum. The 1st year curriculum prior to and after these applied initial changes are shown in Table 1 where the changes made to the prior curriculum (Table 1a) are shown in italics in Table 1b.

Table 1. Curriculum for 1st year BSc Engineering prior to and after the curriculum changes made in 2020. Changes from previous curriculum (a) are shown in italics in (b).

Autumn Semester 1st year	
a. Prior to curriculum change	**b. After the curriculum change**
Calculus I (6 ECTS)	Calculus I (6 ECTS)
Physics I (6 ECTS)	Physics I (6 ECTS)
Chemistry (6 ECTS)	*Linear algebra* (6 ECTS)
Practical Programming in Matlab (6 ECTS)	*Energy* (6 ECTS)
Brainstorming (1 ECTS)	Brainstorming (1 ECTS)
Introduction to Engineering (5 ECTS) (3 weeks)	Introduction to Engineering (5 ECTS) (3 weeks)
Spring Semester 1st year	
a. Prior to curriculum change	**b. After the curriculum change**
Calculus II (6 ECTS)	Calculus II (6 ECTS)
Physics II (6 ECTS)	Physics II (6 ECTS)
Linear Algebra (6 ECTS)	*Engineering programming* (6 ECTS)
Study line specific course (6 ECTS)	Study line specific course (6 ECTS)
Entrepreneurship and Starting New Ventures (6 ECTS) (3 weeks)	Entrepreneurship and Starting New Ventures (6 ECTS) (3 weeks)

Course description

Following is the initial course description and learning outcomes of the 6 ECTS course Energy which was launched in autumn semester 2020.

Course description
At the beginning of the course the students will learn the basics of programming tools, e.g. Matlab to solve engineering problems. This tool will be used in the course in project work. The basics concepts and laws of physics which relate to thermodynamics and heat transfer will be introduced. An emphasis is made on conservation of matter, mass and energy in simple systems. Thermodynamic properties of pure substances and laws of

thermodynamics, and ways of heat transfer will be introduced as well as analysis of energy sources for thermal energy and electricity production.

Learning outcomes:
At the end of the course the students should have knowledge of:
- The fundamentals of engineering which relates to thermodynamics
- Energy and mass conservation in simple engineering systems
- The physics of heat transfer
- Practical programming for solving engineering problems

At the end of the course the students should have competence to:
- Solve simple engineering problems related to mass and energy balance and heat transfer
- Set up and solve simple calculations of energy production, with the use of e.g. practical programming tools
- To present results of calculations in an efficient way

At the end of the course the students should have gained skills to applying engineering methods to solve simple energy related problems.

This course is integrating practical programming tools into thermodynamics and energy technology. In other first semester courses, the students also use Matlab where applicable. To name few examples, the students use Matlab for analyzing measurement data and representing results in Physics lab classes. In Calculus students use Matlab for numerical methods to compute integrals and solve equations (using the bisection method). The tools (Matlab programming for engineering and scientific problem solving) are therefore taught in one course in the first semester and used in the courses taught parallelly. This can be related to the CDIO Standard 3 – Integrated Curriculum.

As seen from the above learning outcomes, the Energy course covers variety of subjects in programming and energy engineering and it has been a challenge to merge all these outcomes into a single 6 ECTS course as described in the following section.

Lessons learned

The course Energy has now been taught 3 times, in the autumn semesters 2020-2022. First two times the course was taught was under challenging circumstances due to to Covid-19 restrictions. The course in 2020 had the Matlab content integrated into the thermodynamic content from day one but the first two weeks were however more focused on getting the fundamentals of Matlab programming. Gradually, the Matlab content was built up and used for problem solving in thermodynamic exercises.

The students experience from the first round, as reported in the student teaching survey, was that students often found this quite overwhelming to be learning programming and thermodynamic simultaneously since for most of the students, both these topics were new to them. It was therefore decided, for the second round of the course Energy in 2021 to divide these topics more and focus on Matlab only for the first 4 weeks and teach thermodynamics and energy technology with Matlab integration for 8 weeks after that. This proved to be a successful change and was taken one step further by splitting the energy course into 4 weeks Matlab course and 8 weeks of Energy course with Matlab integration. This is summarized in Table 2 which shows how the course has developed over the three years period 2020-2022.

Table 2. Setup of the Energy and Matlab course

Autumn 2020	Autumn 2021	Autumn 2022
T-101-ORKA (6 ECTS)	T-101-ORKA (6 ECTS)	Two courses: T-101-MATL (2 ECTS) & T-102-ORKA (4 ECTS)
One course: Matlab programming, thermodynamics and energy technology integrated for 12 weeks	One course: Matlab programming for 4 weeks. Thermodynamics and energy technology with Matlab programming integrated for 8 weeks	Two courses: 1) Matlab programming for 4 weeks. 2) Thermodynamics and energy technology with Matlab programming integrated for 8 weeks

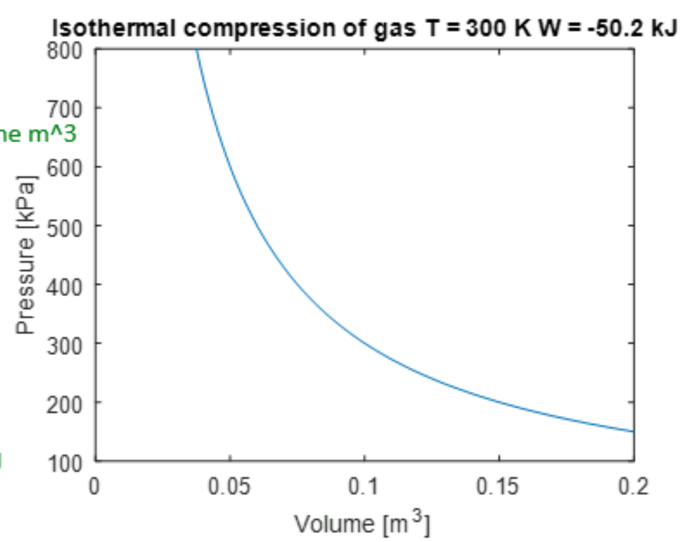
Course assessment and project examples

The course assessment consists of weekly homeworks and quizzes, midterm exams, group project work, activities in problem classes and a final exam. Figure 1 shows examples on how the basics of Matlab programming were used on a thermodynamic and an energy technology problem in the Energy course. The upper figure in Figure 1 shows Matlab code and a plot for an isothermal compression process of an ideal gas. The lower part of Figure 1 shows if-elseif-else statement in Matlab for using a range of velocity values for calculating wind turbine power and efficiency.

```
V1 = 0.2; % m^3
T = 300; % K
p1 = 150; % kPa
p2 = 800; % kPa
V2 = p1/p2*V1 % Final volume m^3
W = p1*V1*log(p1/p2) % kJ


V = linspace(V1,V2);
R = 8.31; % kJ/kg/K
n = p1*V1/R/T; % moles
p = n*R*T./V; % kPa


W2 = n*R*T*log(V2/V1) % kJ
plot(V,p)
xlabel('Volume [m^{3}]')
ylabel('Pressure [kPa]')
title(sprintf('Isothermal compression of ideal gas T = 300 K W = %.1f kJ',W))
```



```
clear, clc, close all
v = linspace(0,40,1000);
Pmax = 2000e3; % kW
rho = 1.2;
D = 90;
p = polyfit([4 15],[0 Pmax],1)
for i = 1:length(v)
   if v(i) < 4
      P(i) = 0;
      eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
   elseif v(i) >= 4 & v(i) < 15
      P(i) = polyval(p,v(i));
      eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
   elseif v(i) >= 15 & v(i) <= 30
      P(i) = Pmax;
      eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
   else
      P(i) = 0;
      eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
   end
end

subplot(1,2,1)
plot(v,P)
xlabel('Wind speed [m/s]')
ylabel('Power [W]')
subplot(1,2,2)
plot(v,eta)
xlabel('Wind speed [m/s]')
ylabel(['Efficiency'])
```

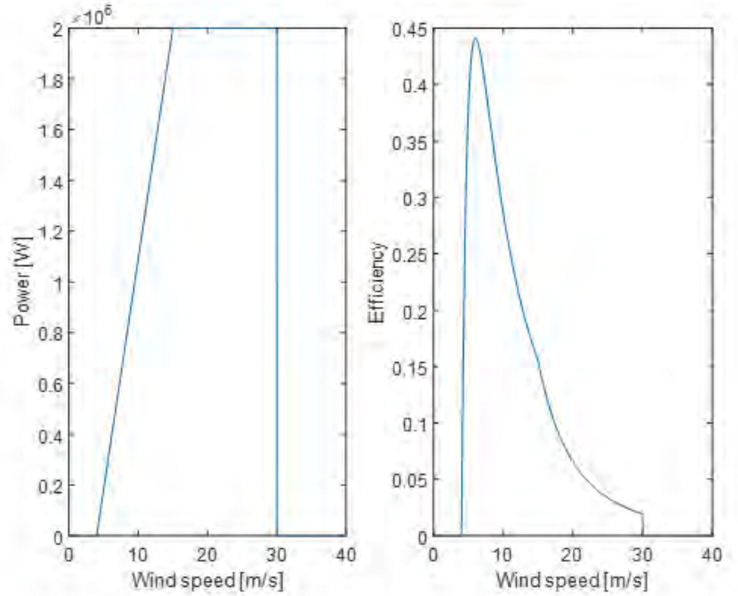


Figure 1. Examples of two problems students solved in the Energy course using Matlab.
Upper: Calculating and plotting an isothermal process of an ideal gas
Lower: Calculating and plotting wind turbine power and efficiency

Examples of larger group projects in the Energy course where Matlab was applied to analyze real world data and present the results in a video and/or report are:

- Estimating wind power potential on a specific site based on wind speed data and how well this power could fulfill the requirement of the use of that site (based on data from a nearby substation)

- Determining power production potential from overflow of an existing hydropower reservoir (Landsvirkjun, 2023). A preliminary design of the plant and to select an appropriate turbine type. Determine how much hydrogen can be produced using this additional electricity produced

These assignments from the Energy course are examples where students used Matlab as a tool to enable a successful solution of the problems they were given. This combines Integrated curriculum and Introduction to engineering which are two of the 12 CDIO standards (CDIO, 2023).

DISCUSSION

Curriculum change was made for the first-year engineering students where 2x6ECTS courses in Matlab programming and Thermodynamics were combined into one 6ECTS course called Energy. The lessons learned from the first two rounds the course was taught, was to prepare the students first in the basic principles of Matlab before energy related topics were introduced. Therefore, we have changed this into 2 new courses, a 2 ECTS course Programming in Matlab and 4 ECTS course Energy. Merging together thermodynamics and Matlab programming in a one course has been an interesting and a challenging process, especially under dynamic and limitating conditions due to Covid-19.

It turned out that integrating these two topics entirely may have been too large step for first-year students starting their university journey where most of them have little or no background in programming. Therefore it was decided to distinguish more between the two topics. In this development, we have however learned, that with 4 weeks of Matlab training the students get enough background to integrate their knowledge into other proceeding courses and work on real world problems. It is also important that Matlab is integrated systematically into the other first year courses to ensure continuity in the curriculum and the student use this useful tool that Matlab programming can be in their science and engineering subjects.

Integrating the curriculum according to the CDIO standards is an important part of the curriculum development at the Department of Engineering at RU and combining these two subjects, introduction to programming and thermodynamics is only one part of the overall CDIO implementation at the department.

In light of the current development related to tackle climate change by energy transition it is essential that all modern engineers have a solid basic understanding of the laws of thermodynamics and energy technology. Also, it is important that engineering students work from the beginning of their study on real life problems and use the tools that have been introduced to them (e.g. Matlab programming) to enable a successful solution to the problems and representation of the results.

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BIOGRAPHICAL INFORMATION

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