Teaching Chemical Engineering Thermodynamics at DTU

How, Why, Impressions, Some Personal Thoughts

Georgios M. Kontogeorgis
Center for Energy Resources Engineering (CERE)
Department of Chemical and Biochemical Engineering
Technical University of Denmark

With great contributions from All "Thermo" Teachers:

Nicolas von Solms
Kaj Thomsen
Wei Yan
Xiaodong Liang
The old guard (our/my teachers)

Fredenslund     Rasmussen           Michelsen          Mollerup
The new generation

Thomsen  von Solms  Yan  Liang
Outline

• Education and Teaching at DTU
• Teaching of Thermodynamics at DTU
• Comparison to other places (vs. survey from WP – Chem.Eng.Educ., 2010, 44(1): 35)
• Impressions and personal thoughts
• Outlook for future and
Conclusions
DTU

• Founded in 1829 by the Danish physicist Hans Christian Ørsted
• Moved to Lyngby in the sixties - 10 km north of Copenhagen
• Leading centre of engineering education and research in Denmark
• Focus on Education – Research – Innovation and Service to authorities
• 6000 students
• 700 Ph.d. students
• 4600 employees
• 19 departments
• Education: 9 B.Eng., 15 B.Sc., >30 M.Sc.
DTU is a National university with several locations
DTU’s 19 Departments

DTU Chemical Engineering
DTU Civil Engineering
DTU Systems Biology (now 2)
DTU Electrical Engineering
DTU Energy Conversion
DTU Management Engineering
DTU Mechanical Engineering
DTU Space
DTU Compute

DTU Chemistry
DTU Environment
DTU Food
DTU Fotonik
DTU Nanotech
DTU Aqua

DTU Physics
DTU Wind Energy
DTU Veterinary
DTU Transport
14 challenges of engineering in the 21st century

- Make solar energy economical
- Provide energy from fusion
- Develop carbon sequestration methods
- Manage the nitrogen cycle
- Provide access to clean water
- Restore and improve urban infrastructure
- Advance health informatics
- Engineer better medicines
- Reverse-engineer the brain
- Prevent nuclear terror
- Secure cyberspace
- Enhance virtual reality
- Advance personalized learning
- Engineer the tools of scientific discovery
Education at DTU

• Bologna system: 3 (BSc) + 2 (MSc) + 3 (PhD)
• Alternatively 3.5 B.Eng. (Diplom)
• Education belongs to DTU – not the Departments!
• All students choose a BSc/B.Eng., then M.Sc.
• B.Sc./B.Eng. in Danish (in principle)
• M.Sc. in English – many foreign students (> 30%)
• No Tuition Fees for EU students
• 3-year PhD studies after M.Sc.
• 5 year studies from abroad recognized as M.Sc. at DTU
Udlandske studerende strømmer til Danmark

Antallet af udlandske studerende, der tager en af dertil, er på 10 år i Danmark, er mere end tredoblet i løbet af 10 år. Det viser nye tal fra Udannelsesministeriet, og den nyhed vækker begejstring på begge sider af det politiske spektrum.

«Det viser, at det fokus, som København har haft de seneste år på at få flere internationale studerende til byen, er lykkebeligendes. Vi har brug for internationale studerende og erhvervsfolk for at skabe mere vækst og flere job i Danmark,» siger Københavns socialdemokratisk overborgmester, Frank Jensen.

Vemstres SU-ordfører, Mads Rørvig, er på samme linje: «Forudsætningen for, at vi kan blive klogere, er, at vi har noget input fra udlandet, og så det synes jeg er rigtig, rigtig fint,» siger han.

Hvorfor Danmark
Men hvorfor vælger de unge præcis Danmark? Medlemmerne af netværket Youth Goodwill Ambassador Corps, der består af 200 internationale studerende fra hele verden, angiver tre grunde:


«En ting er, at det er dedikeret, at de tager hele deres uddannelse i Danmark, men det, der jo også er interessant, er at de har dem integreret i arbejdsmarkedet, så de bliver her bagefter og bidrager til samfundsudviklingen,» påpeger han og tilføjer:

«Det handler om at lave kontakter mellem uddannelsesmiljøerne og virksomhederne. For eksempel at give muligheder for, at man kan tage praktik eller lave opgaver på virksomheder.»

Et af de steder, hvor antallet af udlandske studerende, der færdselser hele deres uddannelse i Danmark, er eksporteret, er VIA University College i Midtjylland, hvor man kan læse en lang række korte og mellemlange videregående ud- dannelser.

«Vi håber meget, at de bliver i Danmark og bidrager til arbejdsmarkedet, forklarer Konstantin Lassithiotakis, direktør i Teknisk/Markantil Højskole, som er en del af VIA og et af de steder med stor koncentration af udlandske studerende.»

Vi har et tæt samarbejde med virksomheder, som er interesserede i udlandske studerende. Både i forhold til praktik og med henblik på at ansette dem, når de er færdiguddannede – enten i Danmark eller i den studerende hjemland, hvor den danske virksomhed så er etableret,» tilføjer han.

VIA regner med, at mindst et tredjedel af de udlandske studerende ender med at blive ansat i en dansk virksomhed – enten i Danmark eller i udlandet.
B.Sc. 15 programs

Bioteknologi
Byggeteknologi
Bygningsdesign
Design og innovation
Elektroteknologi
Fysik og nanoteknologi
Geofysik og Rumteknologi
IT og kommunikationsteknologi
Kemi og teknologi
Matematik og teknologi
Medicin og teknologi
Miljøteknologi
Produktion og konstruktion
Softwareteknologi
Teknisk biomedicin (tidl. Sundhed og Produktion)
Bachelor of Science in Engineering = 180 points

<table>
<thead>
<tr>
<th>Natural sciences</th>
<th>Projects and general courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 ECTS points</td>
<td>45 ECTS points</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technological specialisation courses</th>
<th>Electives courses</th>
</tr>
</thead>
<tbody>
<tr>
<td>45 ECTS points</td>
<td>45 ECTS points</td>
</tr>
</tbody>
</table>
M.Sc. 28 programs (and more...)

- Advanced and Applied Chemistry
- Aquatic Science and Technology
- Architectural Engineering
- Biotechnology
- Chemical and Biochemical Engineering
- Civil Engineering
- Design and Innovation
- Earth and Space Physics Engineering
- Electrical Engineering
- Engineering Design and Applied Mechanics Engineering
- Management
- Environmental Engineering
- Food Technology
- Materials and Manufacturing Engineering
- Medicine and Technology
- Petroleum Engineering
- Pharmaceutical Design and Engineering
- Photonics Engineering
- Physics and Nanotechnology
- Sustainable Energy
- Systems Biology
- Transportation and Logistics
- Wind Energy
# M.Sc. Structure (120 ECTS)

<table>
<thead>
<tr>
<th>Master of Science in Engineering = 120 points</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General competence courses</strong></td>
</tr>
<tr>
<td>Min 30 ECTS points</td>
</tr>
<tr>
<td><strong>Technological specialisation courses</strong></td>
</tr>
<tr>
<td>Min 30 ECTS points</td>
</tr>
<tr>
<td><strong>Master thesis project</strong></td>
</tr>
<tr>
<td>Min 30 ECTS points</td>
</tr>
<tr>
<td><strong>Electives courses</strong></td>
</tr>
<tr>
<td>Max 30 ECTS points</td>
</tr>
</tbody>
</table>
**Teaching at DTU – the 4-hour blocks!**

<table>
<thead>
<tr>
<th>Time</th>
<th>Monday</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
<th>Friday</th>
</tr>
</thead>
<tbody>
<tr>
<td>8.00-12.00</td>
<td>1A</td>
<td>3A</td>
<td>5A</td>
<td>2B</td>
<td>4B</td>
</tr>
<tr>
<td>13.-17.00</td>
<td>2A</td>
<td>4A</td>
<td>5B</td>
<td>1B</td>
<td>3B</td>
</tr>
</tbody>
</table>

5p. + 7.5p. courses: one module
10p. course: two modules
## Grade scale

### Old scale:

<table>
<thead>
<tr>
<th>13-skala</th>
<th>00</th>
<th>03</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>13</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-trins</td>
<td>-3</td>
<td>00</td>
<td>00</td>
<td>2</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>10</td>
<td>12</td>
<td>12</td>
</tr>
</tbody>
</table>

### New scale:

<table>
<thead>
<tr>
<th>Karakter</th>
<th>Betegnelse</th>
<th>ECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Den fremragende præstation</td>
<td>A</td>
</tr>
<tr>
<td>10</td>
<td>Den fortrinlige præstation</td>
<td>B</td>
</tr>
<tr>
<td>7</td>
<td>Den gode præstation</td>
<td>C</td>
</tr>
<tr>
<td>4</td>
<td>Den jævne præstation</td>
<td>D</td>
</tr>
<tr>
<td>02</td>
<td>Den tilstrækkelige præstation</td>
<td>E</td>
</tr>
<tr>
<td>00</td>
<td>Den utilstrækkelige præstation</td>
<td>Fx</td>
</tr>
<tr>
<td>-3</td>
<td>Den ringe præstation</td>
<td>F</td>
</tr>
</tbody>
</table>
Special characteristics of teaching and examinations at DTU

• Campusnet – DTU intranet where all material is uploaded
• All courses are evaluated every semester (see next)
• Most exams are ”open book” exams
• Written 4-h exams in some courses
• Many project-related courses, some with group work (4-5 students)
• All project reports uploaded in Campusnet for ”plagiarism” check
• Typically for all examinations: answers corrected by the teacher(s) + external (outside DTU) examiner
• DTU often experiments with new things – now it is ”digital” (computer-based) exams (in few years for all written exams) – we have also midterm evaluation and exam evaluation
# Results: 28315 Applied Colloid and Surface Chemistry E12

## Schema A

### Course evaluation

#### Statistics
- 48 could answer this evaluation form
- 22 have answered this evaluation form
- 1 did not follow the course
- 45.83% answer percentage: 22 / (48 - 1)

<table>
<thead>
<tr>
<th>1</th>
<th>I think I am learning a lot in this course (22 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>8</td>
<td>36.36%</td>
</tr>
<tr>
<td>1</td>
<td>4.55%</td>
</tr>
<tr>
<td>1</td>
<td>4.55%</td>
</tr>
<tr>
<td>0</td>
<td>Strongly disagree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.2</th>
<th>I think the teaching method encourages my active participation (22 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>1</td>
<td>40.91%</td>
</tr>
<tr>
<td>1</td>
<td>4.55%</td>
</tr>
<tr>
<td>3</td>
<td>13.64%</td>
</tr>
<tr>
<td>0</td>
<td>Strongly disagree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.3</th>
<th>I think the teaching material is good (22 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>7</td>
<td>31.82%</td>
</tr>
<tr>
<td>3</td>
<td>13.64%</td>
</tr>
<tr>
<td>2</td>
<td>9.09%</td>
</tr>
<tr>
<td>0</td>
<td>Strongly disagree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.4</th>
<th>I think that throughout the course, the teacher/s have clearly communicated to me where I stand academically (22 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>2</td>
<td>22.73%</td>
</tr>
<tr>
<td>6</td>
<td>27.27%</td>
</tr>
<tr>
<td>0</td>
<td>Strongly disagree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.5</th>
<th>I think the teacher/s create/s good continuity between the different teaching activities (20 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>10</td>
<td>50%</td>
</tr>
<tr>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>1</td>
<td>5%</td>
</tr>
<tr>
<td>0</td>
<td>Strongly disagree</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.6</th>
<th>5 points is equivalent to 9 hrs./week (45 hrs./week in the three-week period). I think my performance during the course is (21 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Much less</td>
</tr>
<tr>
<td>4</td>
<td>71.43%</td>
</tr>
<tr>
<td>15</td>
<td>19.05%</td>
</tr>
<tr>
<td>1</td>
<td>4.76%</td>
</tr>
<tr>
<td>0</td>
<td>Much more</td>
</tr>
<tr>
<td>0</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.7</th>
<th>I think the course description's prerequisites are (21 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Too low</td>
</tr>
<tr>
<td>4</td>
<td>4.76%</td>
</tr>
<tr>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>20</td>
<td>95.24%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>1.8</th>
<th>I think this is a good course (22 answers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Strongly agree</td>
</tr>
<tr>
<td>10</td>
<td>45.45%</td>
</tr>
<tr>
<td>0</td>
<td>0.00%</td>
</tr>
<tr>
<td>2</td>
<td>9.09%</td>
</tr>
</tbody>
</table>
Results: 28315 Applied Colloid and Surface Chemistry E12

Schema B

Georgios Kontogeorgis: Teacher

Statistics
48 could answer this evaluation form
19 have answered this evaluation form
1 did not follow the course
39,58% answer percentage: 19 / (48 - 1)

1 Lecture/Classroom instruction
1.1 I think that the teaching gives me a good grasp of the academic content of the course (19 answers)
   Strongly agree 12
   6 33,33%
   1 5,26%
   0 0,00%

   Strongly disagree 0
   0 0,00%

1.2 I think the teacher is good at communicating the subject (19 answers)
   Strongly agree 10
   9 52,63%
   0 0,00%
   0 0,00%

   Strongly disagree 0
   0 0,00%

1.3 I think the teacher motivates us to actively follow the class (19 answers)
   Strongly agree 10
   7 52,63%
   0 0,00%
   2 10,53%
   0 0,00%

   Strongly disagree 0
   0 0,00%

2 Practical assignments/Lab courses/Course tutorial/Group work/Project work
2.1 I think that I generally understand what I am to do in our practical assignments/lab courses/group computation/group work/project work (19 answers)
   Strongly agree 10
   6 52,63%
   3 15,79%
   0 0,00%

   Strongly disagree 0
   0 0,00%

2.2 I think the teacher is good at helping me understand the academic content (19 answers)
   Strongly agree 11
   6 57,89%
   2 10,53%
   0 0,00%

   Strongly disagree 0
   0 0,00%

2.3 I think the teacher gives me useful feedback on my work (19 answers)
   Strongly agree 8
   7 42,11%
   4 21,05%
   0 0,00%

   Strongly disagree 0
   0 0,00%

3 The teachers communication skills in English
3.1 I think the teacher's communication skills in English are good (19 answers)
   Strongly agree 8
   6 42,11%
   1 5,26%
   1 5,26%

   Strongly disagree 0
   0 0,00%

3.2 You can write additional comments on the teaching of the teacher in question here (3 answers)

   Jeg er blevet overrasket over at vi skal lave så mange udledninger i reneopgaverne. Jeg skriver kommentaren her da det har været i dine reneopgave at udledninger har været.
Results: 28315 Applied Colloid and Surface Chemistry E12

Schema C

Comments:

Statistics
48 could answer this evaluation form
17 have answered this evaluation form
1 did not follow the course
35,42% answer percentage: 17 / (48 - 1)

1 Qualitative comments
1.1 What went well – and why? (6 answers)
- Generally, I like the course and how the topics are linked to industrial applications each lecture.
- Super kursus, som er rigtig spændende.
- Good lectures with variation between exercise and presentation. The topic is difficult with a lot of theory and equations, but it is given in a good way.
- Jeg synes forholdet mellem forlæsning og gruppearbejde er godt så man hør god tid til at nå at regne opgaverne.
- Det er godt med de mange øvelser, så man forstår stoffet. Det er en teknisk gennemgang, ikke det er vær­
- tilstrækkeligt.
- Og det er ligeledes fint at lektionen deles op, så man først får undervisning, derefter regneopgaver, og därefter undervisning igen. Det holder een på dupperne.
- The course has a very good structure - alternating lectures and problem solving.

1.2 What did not go so well – and why? (4 answers)
- Unfortunately, I think the book is really difficult to read, but I like the notes.
- Some of the slideshows were long and contained some irrelevant slide, and also slides that basically said
- the same thing. You could make it a bit simpler and a bit more concrete.
- Der er ikke så meget ping-pong mellem læerer og elever.
- Undervisningerne kunne godt opførlre til flere spørgsmål undervejs.
- I did not particularly enjoy the course just because in general I find that I do not enjoy chemistry.
- Also, having a four-hour final exam worth 100% of the final grade is too stressful.

1.3 What changes would you suggest for the next time the course is offered? (6 answers)
- I would prefer one calculation session each time instead of two separate sessions.
- Jeg vil foreslå at fjærne de blyanter, da er på slides og i bogen. De kan godt få det til at virke lidt
- overskueligt.
- You tend to lose the big picture during the semester due to all the equations and theory. (Especially in the
- major topics as stability which is divided in four part). After each topic make an overview of the essential
- containing the most important equations and when to use them. Hand it out to the students, and it will be
- a valuable tool for the exam and the future.
- Søren Kill viste ved første undervisningsgang hvordan mætik kan kluppe sammen, ved blot at ændre pH
- værdien. Dette lille eksempel var godt, og nogle flere tilsvarende eksempler kunne være
- interessant/relevante.
- possibly try to phase out the book and make the notes a bit more in depth, having two sets of literature
- where there are fairly many overlaps gives a bit much unnecessary reading. could be nice to have the
- answers to the problems in the notes as well so it is easily seen if the problem is solved correctly (and still
- having the full solutions uploaded later...)
- Offer assignments that are worth a certain percentage of the course grade so that the exam is not fully
- weighted.
### Teaching Thermodynamics – at a glance!

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Name</th>
<th>Type (ECTS)</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>28221 28322</td>
<td>Chemical Eng. Thermodynamics</td>
<td>BSc (5) Beng (5)</td>
<td>Properties of pure compounds and mixtures, Laws of thermodynamics</td>
</tr>
<tr>
<td>28423</td>
<td>Phase Equilibria for non-ideal mixtures</td>
<td>MSc (5)</td>
<td>Thermodynamic models</td>
</tr>
<tr>
<td>28909</td>
<td>Thermodynamic models: Fundamentals and Computational aspects</td>
<td>PhD (7.5) – August course</td>
<td>Coding models, flash routines</td>
</tr>
<tr>
<td>28928</td>
<td>Electrolyte Thermodynamics</td>
<td>PhD (7.5) - Any time</td>
<td>Electrolytes</td>
</tr>
<tr>
<td>28917</td>
<td>Statistical Thermodynamics</td>
<td>PhD (5)</td>
<td>Statistical aspects</td>
</tr>
<tr>
<td>26222</td>
<td>Physical Chemistry 2</td>
<td>BSc (5)</td>
<td><em>Gibbs phase rule, Mixtures, activities, Electrochemistry</em></td>
</tr>
</tbody>
</table>
Gibbs solved 2/3 of the thermodynamic problem 150 years ago!

J. Willard Gibbs
One of the Greatest Scientists Of All times!

Gilbert Lewis
(1875-1946)

We are still struggling with the third step!!

\[ f_i^a = f_i^b \quad i = 1, 2, \ldots, N \]

Vapor-liquid equilibria

\[ y_i \Phi_i^V = x_i \Phi_i^L \quad i = 1, 2, \ldots, N \]

Figure 1-3 Three-step application of thermodynamics to phase-equilibrium problems.
# Teaching Thermodynamics – Content

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Name</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>28221 28322</td>
<td>Chemical Eng. Thermodynamics</td>
<td>Pure compounds, mixtures, cycles, flash calculations, process applications e.g. refrigeration, ternary LLE, activity coefficient models</td>
</tr>
<tr>
<td>28423</td>
<td>Phase Equilibria for non-ideal mixtures</td>
<td>Cubic and non-cubic EoS (SAFT, CPA), mixing rules for cubic EoS, polymers, environmental thermodynamics, electrolytes</td>
</tr>
<tr>
<td>28909</td>
<td>Thermodynamic models: Fundamentals and Computational aspects</td>
<td>Computational methods : PT flash, Multiphase flash, stability analysis, chemical equilibrium</td>
</tr>
<tr>
<td>28928</td>
<td>Electrolyte Thermodynamics</td>
<td>Electrolytes fundamentals, phase diagrams and models</td>
</tr>
<tr>
<td>28917</td>
<td>Statistical Thermodynamics</td>
<td>Fundamentals, CS EoS, Monte Carlo simulations, SAFT</td>
</tr>
</tbody>
</table>
## Teaching Thermodynamics – How

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Name</th>
<th>Teaching form</th>
<th>Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>28221</td>
<td>Chemical Eng. Thermodynamics</td>
<td>Lectures + computer-based problems using spreadsheets (excel) for simulation</td>
<td>Reports + oral examination</td>
</tr>
<tr>
<td>28322</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28423</td>
<td>Phase Equilibria for non-ideal mixtures</td>
<td>Lectures + classroom exercises + computer exercises (SPECS)</td>
<td>Evaluation of exercises + final report (on topic of interest of students)</td>
</tr>
<tr>
<td>28909</td>
<td>Thermodynamic models: Fundamentals and Computational aspects</td>
<td>Lectures + computer exercises in teams of two – own programming</td>
<td>Evaluation of exercises + reports</td>
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<tr>
<td>28928</td>
<td>Electrolyte Thermodynamics</td>
<td>Own study of Notes</td>
<td>Evaluation of exercises + reports – takes 2-3 months to complete the course</td>
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<tr>
<td>28917</td>
<td>Statistical Thermodynamics</td>
<td>Lectures, projects, homework problems, self-study</td>
<td>Evaluation of exercises + reports - projects</td>
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</table>
## Teaching Thermodynamics – Special Issues

<table>
<thead>
<tr>
<th>Course Number</th>
<th>Name</th>
<th>Special Issues</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>28221 28322</td>
<td>Chemical Eng. Thermodynamics</td>
<td>Use of excel modules</td>
<td>Own teaching material + one other book</td>
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<tr>
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<td>No written examination – only reports</td>
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<tr>
<td>28423</td>
<td>Phase Equilibria for non-ideal mixtures</td>
<td>Use of SPECS</td>
<td>Own teaching material</td>
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<tr>
<td>28909</td>
<td>Thermodynamic models: Fundamentals and Computational aspects</td>
<td>Own coding (Fortran, MATLAB), many externals incl. Industrial participants</td>
<td>Own teaching material</td>
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<tr>
<td>28928</td>
<td>Electrolyte Thermodynamics</td>
<td>On-line course</td>
<td>Own teaching material</td>
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<tr>
<td>28917</td>
<td>Statistical Thermodynamics</td>
<td>Sometimes student-defined projects</td>
<td>Book from literature</td>
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<tr>
<td>Course Number</td>
<td>Name</td>
<td>Book</td>
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<tr>
<td>28221 28322</td>
<td>Chemical Eng. Thermodynamics</td>
<td>Elliott &amp; Lira + Michelsen Notes</td>
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<tr>
<td>28423</td>
<td>Phase Equilibria for non-ideal mixtures</td>
<td>Kontogeorgis &amp; Folas K. Thomsen Notes</td>
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<td>28909</td>
<td>Thermodynamic models: Fundamentals and Computational aspects</td>
<td>Michelsen &amp; Mollerup</td>
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<td>28928</td>
<td>Electrolyte Thermodynamics</td>
<td>K. Thomsen Notes</td>
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<tr>
<td>28917</td>
<td>Statistical Thermodynamics</td>
<td>McQuarrie</td>
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</table>
Books in Thermodynamics (by CERE staff)

Mostly used in the PhD Course:

28909 (2007)

28423 (2010)

Kaj Thomsen: Notes on Electrolyte Thermodynamics
(very extensive) +
special course with exercises

M.L. Michelsen: Notes on Applied Thermodynamics with exercises
The Michelsen course... without Michelsen (for second time)

24 participants, 4 from companies, 8 countries

+ Xiaodong
Alexander
Philip
Duncan
Louise
Christian

Photos: Christian Carlsson
# Algorithms-Models PhD Course

Participants from 25+ Different Countries in 6 years!

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<td>Participants – Total</td>
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<td>17</td>
<td>26</td>
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<tr>
<td>From Industry</td>
<td>4</td>
<td>13</td>
<td>8</td>
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<tr>
<td>From academia</td>
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<tr>
<td>From CERE</td>
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<td>4</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>5</td>
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<tr>
<td>From DTU – other</td>
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<td>2</td>
<td>1</td>
<td>2</td>
<td>-</td>
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<tr>
<td>How many countries-Affiliation</td>
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<td>10</td>
<td>9</td>
<td>12</td>
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<td>9</td>
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</table>
DTU vs. Rest of the world (survey)

- We have also "the two basic" courses – but also a PhD course on computational aspects
- We have more additional specialized thermodynamic courses
- Not much on biological systems (similar to Europe)
- SM and MS – to limited degree but we have them
- Similarly to others, no experimental element in the courses (despite much experimental thermodynamics in research)
- More PBL in USA than in Europe – we also are based much on PBL
DTU vs. Rest of the world (survey) – The Books

- We use Elliott and Lira like 14 US and none European universities – in one of the courses
- We do not use Sandler and have abandoned long time ago the most popular Smith-van Ness-Abbott book
- We recommend Prausnitz el al. in our advanced courses
- Atkins is used in Physical Chemistry courses – not in thermodynamics
- We have lots of own books/own book material
Industrial Requirements for Thermodynamics and Transport Properties

Eric Hendriks,*† Georgios M. Kontogeorgis,‡ Ralf Dohrn,§ Jean-Charles de Hemtinne,‖ Ioannis G. Economou,§ Ljudmila Fele Žilnik,§ and Velisa Vesovic¥

Shell Global Solutions, Shell Technology Centre Amsterdam, Grasweg 3, 1031 HW Amsterdam, The Netherlands, Centre for Energy Resources Engineering (CERE), Department of Chemical and Biochemical Engineering, Technical University of Denmark, DK-2800, Lyngby, Denmark, Bayer Technology Services GmbH, Process Technology, Kinetics, Properties & Modeling, Building B310, D-51368 Leverkusen, Germany, IFP, 1 & 4 Avenue de Bois-Préau, 92852 Rueil-Malmaison Cedex, France, The Petroleum Institute, Department of Chemical Engineering, P.O. Box 2533, Abu Dhabi, United Arab Emirates, National Institute of Chemistry, Department of Catalysis and Reaction Engineering, P.O. Box 660, SI-1001 Ljubljana, Slovenia, and Department of Earth Science and Engineering, Imperial College London, London SW7 2AZ, United Kingdom

Project carried out by the Task Group on Industrial Perspectives under the Working Party on Thermodynamics and Transport Properties (http://www.wp-ttp.dk) of EFCE
Education: Make people aware of the practical consequences of good and wrong thermodynamics – at all levels (undergraduate, postgraduate, professional)

“The students should e.g. be taught in which cases results are reliable and how to distinguish between a good and a bad process”

Molecular simulation: A true effort is needed in order to make these tools readily available to industry (non-experts) – Currently Molecular simulation techniques do not appear to receive high industrial interest
What can be done next? – Bridge the gap between academia and industry

• **Education**
  – Define some minimum knowledge required for Chem Eng, and propose ways to achieve it
  – Promote the employment of young experts (PhD) by chemical industries
  – Propose short courses for professionals to the basics of molecular thermodynamics & more

• **Continue and improve communication**
  – National WP meetings & co-ordination with EFCE

• **More discussion with industry** – more/encourage participation of industrial experts in Conferences on Thermodynamics and Transport properties (*do we have too many conferences?*)
Conclusions & Some personal thoughts

- At DTU we have three basic thermodynamic courses at BSc/BEng, MSc and PhD level
- About 15-30 students/semester follow these courses
- It is actually possible to graduate as Chemical Engineer from DTU without any of these "basic" thermodynamic courses (due to the system we have)
- Courses at DTU are not always taken at a "specific order" (for the BSc and MSc levels)
- Computational tools and PBL are used in all of these courses - diverse tools are used (Excel modules, FORTRAN, MATLAB, in-house software/SPECS,...)
- All of these courses are assessed based on exercises/reports, etc. and none of them has a written examination
Conclusions & Some personal thoughts

• We have several specialized thermo courses as well as several physical chemistry courses (1,2,3..) with substantial thermodynamic content

• Molecular simulation courses have been given as PhD courses with guest teachers (Economou, Mavratzas)

• We have found it difficult to teach based on ”previously published” books and we have abandoned Smith et al. book many years ago

• Teaching is very much based on ”own” material and this includes two own books and two sets of ”almost book-form” based Notes on Electrolytes (Kaj Thomsen) and Basic Thermodynamics (Michael L. Michelsen)